(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 270 522 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
30.05.2012 Bulletin 2012/22

(21) Application number: **09164537.4**

(22) Date of filing: **03.07.2009**

(51) Int Cl.:
H02P 21/14 *(2006.01)* ***H02P 23/14*** *(2006.01)*
G01R 27/02 *(2006.01)* ***G01R 27/08*** *(2006.01)*
G01R 31/34 *(2006.01)*

(54) **Induction motor parameter identification**

Asynchronmotor-Parameteridentifizierung

Identification de paramètre de moteur à induction

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO SE SI SK SM TR

(43) Date of publication of application:
05.01.2011 Bulletin 2011/01

(73) Proprietor: **ABB Oy**
00380 Helsinki (FI)

(72) Inventor: **Heikkilä, Samuli**
00420 Helsinki (FI)

(74) Representative: **Valkeiskangas, Tapio Lassi Paavali**
Kolster Oy Ab
Iso Roobertinkatu 23
P.O. Box 148
00121 Helsinki (FI)

(56) References cited:
EP-A- 1 729 141
DE-A1- 10 254 940
KR-A- 20040 084 083
WO-A-03/047084
JP-A- 62 042 076
US-A- 5 594 670

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 2 270 522 B1

Description

FIELD OF THE INVENTION

[0001] The present invention relates to a method of identifying motor parameters, and more particularly to a method with which parameters of an induction motor can be identified without rotating the motor.

BACKGROUND OF THE INVENTION

[0002] When a frequency converter or a similar device is used for controlling the motion of a motor, the motor parameters need to be known. The machine parameters are needed in control algorithms of the converter for accurate control of the load. The parameters of the machine can be identified using an identification procedure during the commissioning of the drive. In this identification run the converter performs one or more tests on the machine and estimates the parameters needed for control.

[0003] In some situations the load connected to the machine causes some restrictions to the drive so that the identification procedure can not be carried out. The load connected to the controlled motor produces counter torque, which disturbs the identification run to the extent that the identification procedure does not provide accurate results enabling precise control of the motor. It might also happen that the identification run can not be performed with the load at all due to maximum speed and/or maximum torque limits set for the load. In these situations the identification run would require that the controlled machine is completely taken off from the load. This is often cumbersome and sometimes even impossible if the machine to the controlled is an integral part of the mechanics of the load.

[0004] For these purposes, frequency converters may have an option for a stand-still identification procedure in which the rotor of the machine is not rotated. However, the stand-still procedures are able to identify only some of the parameters of the motor while other parameters are calculated using rated values of the machine.

[0005] Figure 1 shows an L-equivalent circuit of an induction machine. The stator resistance R_S of the equivalent circuit can be quite easily identified using DC magnetization current, i.e. stator current i_s, produced with a constant stator voltage u_S. Rotor resistance R_R and stray inductance σL_s can be identified using a DC current with summed pulsed current or with some other injected current.

[0006] The problem relating to the known stand-still identification methods is that the measurement of main inductance L_M and the rotor time constant τ_r ($=L_M/R_R$) depending thereon is very tricky because the machine can not be rotated. This is due to the fact that in stand-still methods the used stator current pulses are almost entirely summed with opposing phases to the rotor current. This means that the corresponding changes in the magnetizing current i_m are relatively small and thus the response from the main inductance to the test pulses is poor.

[0007] The known stand-still methods cannot achieve satisfying estimates for the main inductance and rotor time constant, and these parameters are usually approximated from slip frequency and power factor calculated from the rated values of the machine or from the *cos* θ value given as the rated value. On the other hand, the rated values are not necessarily exact so that the values obtained for the main inductance and rotor time constant with the known stand-still identification methods are inaccurate, which is reflected as a poorer performance of the control when compared to the performance achieved with parameters obtained in identification runs performed with rotating machines.

[0008] The accuracy of the voltage measurement should increase considerably so that sufficiently accurate estimates for the main inductance L_M or rotor time constant τ_r could be calculated in stand-still methods. The increase in voltage accuracy is hard to achieve since, due to reduced costs, the output voltage in frequency converters is typically calculated using a measured DC bus voltage and output switch combination. In this kind of measurement commutation delays and threshold voltages cause inaccuracies to the voltage measurement. These inaccuracies can be quite considerable when compared with the voltage response from the main inductance at the injection frequency.

[0009] Document DE10254940 discloses a method for estimating inductances of an induction machine. The estimation is based in DC-magnetization of the machine.

[0010] Document US5594670 discloses a method for estimating parameters of an induction machine while the machine is rotating.

BRIEF DESCRIPTION OF THE INVENTION

[0011] An object of the present invention is to provide a method and an arrangement for implementing the method so as to solve the above problems. The objects of the invention are achieved by a method and an arrangement, which are characterized by what is stated in the independent claims 1 and 17. The preferred embodiments of the invention are disclosed in the dependent claims.

[0012] The invention is based on the idea of indirect measurement of decaying counter voltage of an induction machine. With the method and apparatus of the invention, the parameters required for control of an induction machine can be

identified without rotating the machine.

[0013] The method and apparatus of the invention eliminate the above problems relating to inaccuracies of estimated main inductance and rotor time constant without need to increase the accuracy of voltage measurement. The present invention provides a way to determine directly the rotor time constant, after which the main inductance can be also estimated if the rotor resistance is known. An embodiment of the invention also provides a method for determining the rotor resistance. Further, an embodiment of the present invention also provides a method for calculating the threshold voltages more accurately than before.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] In the following the invention will be described in greater detail by means of preferred embodiments with reference to the attached drawings, in which

Figure 1 shows an equivalent circuit of an induction machine;
Figure 2 shows stator current and rotor flux waveforms in an embodiment of the present invention;
Figures 3, 4, 5 and 6 show stator current waveforms in embodiments of the present invention;
Figure 7 shows a waveform of magnetizing current in an embodiment of the present invention;
Figure 8 shows stator current waveforms in another embodiment of the present invention;
Figure 9 shows stator current waveforms and rotor flux waveforms in an embodiment of the present invention, and
Figure 10 shows an example of a control system for carrying out the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0015] In the following description, the method of the invention is first used to determine the rotor time constant, then a description is given on how to estimate rotor resistance and threshold voltages. In further sections of the description, the invention is used in connection with determining the rotor time constant independently of the other parameters of the induction machine, and finally a description is given on the calculation of the main inductance from the results obtained with the method of the invention. The description also includes an example of a control system of a frequency converter for carrying out the method of the invention.

Rotor time constant

[0016] The present invention is based on indirectly measuring the decaying counter voltage of an induction machine when the power stage of a frequency converter is made inactive, i.e. the power switches are controlled to off-state when the machine is magnetized. The magnetization of the machine has been carried out so long that the flux of the machine is in steady state before passivating the power stage of the inverter or frequency converter. According to the invention, DC magnetization is provided to the induction machine with the inverter and controlling the power semiconductors of the inverter to off-state.

[0017] Immediately after the power stage has been passivated, the stator current commutates for a short period of time to the free-wheeling diodes connected in anti-parallel with the controlled switches. The current vector is quickly reduced to zero since there is a voltage in the machine terminals, which equals to the used DC voltage and has an opposing polarity with respect to the stator current as long as the diodes carry the current. The decaying of the current to zero lasts typically from 200 to 300 μs and the rotor flux does not fall considerably during that period.

[0018] When the current reaches zero, the magnitude of the rotor flux is:

$$\psi_R = L_M i_{dc_magn} = R_R \tau_r i_{dc_magn} \quad (1)$$

where i_{dc_magn} is the magnetizing current fed to the machine before passivating the power stage.

[0019] Let us assume that after the passivating at time instant t = to the current has dropped to zero. After that time instant the rotor flux of the machine decays with a time constant τ_r according to the exponent law:

$$\psi_R(t) = \psi_R e^{-(t-t_0)/\tau_r} = L_M i_{dc_magn} e^{-(t-t_0)/\tau_r} = R_R \tau_r i_{dc_magn} e^{-(t-t_0)/\tau_r} . \quad (2)$$

[0020] The decaying of the rotor flux induces a voltage to the terminals of the machine, which can be calculated using dynamic state equation of the machine:

$$u_{sd} = (R_s + R_R) i_{sd} + \sigma L_s \frac{di_{sd}}{dt} - \frac{\psi_R}{\tau_r} \quad (3)$$

in which u_{sd} and i_{sd} are the stator voltage and stator current components in the direction of both rotor flux and magnetizing current.

[0021] Since the current and the derivative of the current are zero, according to (3):

$$u_{sd} = -\frac{\psi_R}{\tau_r} . \quad (4)$$

[0022] The instantaneous voltage in the machine terminals is thus directly proportional to the magnitude of the rotor flux. Thus, when the rotor flux decays, the stator voltage decays according to the same exponential law. By measuring the terminal voltage of the machine at two different time instants it would basically be possible to determine the rotor time constant. The voltage of equation (4) is so low (typically less than 10V) that such voltages can not be measured in frequency converters without costly special arrangements.

[0023] In the present invention, this problem is solved by measuring said instant indirectly. According to the present invention, all the output phases of the inverter are controlled to the same potential for providing a zero voltage vector. Thus the power stage of the inverter is activated and all output phases are controlled either to a positive or negative DC voltage of the intermediate circuit for producing a zero vector. Since the threshold voltages of the diodes and transistors of the power stage are smaller than the induction voltage (4), the stator current starts to flow when the terminal voltage of the machine is equal to the threshold voltage u_{th} acting over the power semiconductor components

$$u_{sd} = -u_{th} . \quad (5)$$

[0024] When the zero voltage vector is in use, current follows the equation:

$$-u_{th} = (R_s + R_R) i_{sd} + \sigma L_s \frac{di_{sd}}{dt} - \frac{\psi_R}{\tau_r} . \quad (6)$$

[0025] As shown in Figure 2, the current thus rises in the direction of the original magnetizing current with the time constant $\sigma L_s / (R_s + R_R)$, which is considerably smaller than the rotor time constant $\tau_r = L_M / R_R$. After a particular time the current reaches its maximum value i_{sdz_max}, after which it starts to drop again since the rotor flux is still decaying and forcing the derivate of the current finally to be negative in equation (6).

[0026] In Figure 2 the current has its maximum value at time instant t = t_z, at which instant the derivate of the current is zero :

$$\left(\frac{di_{sd}}{dt}\right)_{t=t_z} = 0 . \qquad (7)$$

[0027] At the instant of the current maximum, the stray inductance term is eliminated from equation (6). Thus, at time instant t_Z equation (6) can be written as

$$-u_{th} = (R_s + R_R) i_{sdz_max} - \frac{\psi_R(t_z)}{\tau_r} . \qquad (8)$$

[0028] The magnitude of the rotor flux at time instant t_Z depends on the maximum value of the current i_{sdz_max} and the rotor time constant in the following way:

$$\psi_R(t_z) = (u_{th} + (R_s + R_R) i_{sdz_max}) \tau_r . \qquad (9)$$

[0029] If it is assumed that the increase of the stator current during the zero vector does not considerably slow down the decaying of the rotor flux before the time instant t_Z, the exponential law of equation (2) should produce a value according to (9) for the rotor flux. In other words:

$$\psi_R(t_z) = R_R \tau_r i_{dc_magn} e^{-(t_z - t_0)/\tau_r} = (u_{th} + (R_s + R_R) i_{sdz_max}) \tau_r . \qquad (10)$$

[0030] The rotor time constant can now be solved from equation (10) in the following way:

$$e^{-(t_z - t_0)/\tau_r} = \frac{u_{th} + (R_s + R_R) i_{sdz_max}}{R_R i_{dc_magn}}$$

$$\Rightarrow \tau_r = \frac{t_z - t_0}{\ln\left(\frac{R_R i_{dc_magn}}{u_{th} + (R_s + R_R) i_{sdz_max}}\right)} \qquad (11)$$

[0031] The decaying of the rotor flux due to the increase of the stator current during time period $t_{z0} \ldots t_z$ and the resulting error in the estimate of equation (11) can be taken into account by using the exponential law only during the activating of the zero vector (i.e. to t_{z0}) and by calculating then the change in the rotor flux from the stator current:

$$\psi_R(t_z) = R_R \tau_r i_{dc_magn} e^{-(t_z - t_0)/\tau_r} + \frac{1}{\tau_r} \int_{t_{z0}}^{t_z} (L_M i_{sd}(t) - \psi_R(t)) dt$$
$$= R_R \tau_r i_{dc_magn} e^{-(t_z - t_0)/\tau_r} + \int_{t_{z0}}^{t_z} \left(R_R i_{sd}(t) - \frac{\psi_R(t)}{\tau_r} \right) dt \quad (12)$$

[0032] The magnitude of the voltage component Ψ_R/τ_r in the integral can be approximated as a constant during period $t_{z0} \cdots t_z$. This magnitude can be solved from equation (8) at the time instant t_z, which is the time instant of the maximum current:

$$\frac{\psi_R(t)}{\tau_r} \approx \frac{\psi_R(t_z)}{\tau_r} = u_{th} + (R_s + R_R) i_{sdz_max} \quad (13)$$

[0033] By inserting equation (13) into the integral expression of equation (12), the rotor flux according to the exponential law can be extrapolated to the time instant t_z in the following way:

$$\psi_R(t_z) = R_R \tau_r i_{dc_magn} e^{-t_{z0}/\tau_r} + R_R \int_{t_{z0}}^{t_z} i_{sd}(t) dt$$
$$- \left(u_{th} + (R_s + R_R) i_{sdz_max} \right) (t_z - t_{z0}) \quad (14)$$

[0034] Based on equation (14), a rotor time constant should be calculated, which gives a rotor flux with the same magnitude as equation (9) at the time instant t_z, i.e.:

$$R_R \tau_r i_{dc_magn} e^{-(t_{z0}-t_0)/\tau_r} + R_R \int_{t_{z0}}^{t_z} i_{sd}(t)dt - \left(u_{th} + (R_s + R_R) i_{sdz_max}\right)(t_z - t_{z0})$$
$$= \left(u_{th} + (R_s + R_R) i_{sdz_max}\right)\tau_r$$

$$\Leftrightarrow R_R \tau_r i_{dc_magn} e^{-(t_{z0}-t_0)/\tau_r}$$
$$= \left(u_{th} + (R_s + R_R) i_{sdz_max}\right)(\tau_r + t_z - t_{z0}) - R_R \int_{t_{z0}}^{t_z} i_{sd}(t)dt$$

$$\Rightarrow \tau_r = \frac{t_{z0} - t_0}{\ln\left(\frac{R_R \tau_r i_{dc_magn}}{\left(u_{th} + (R_s + R_R) i_{sdz_max}\right)(\tau_r + t_z - t_{z0}) - R_R \int_{t_{z0}}^{t_z} i_{sd}(t)dt}\right)}. \quad (15)$$

[0035] As shown, the more precise rotor time constant can not be solved in the closed form from equation (15). It can, however, be solved numerically using a suitable iteration method. Another possibility is to use a calculated estimate of the rotor time constant on the right side of equation (15). The calculated estimate can be calculated for example from rated values of the machine. The use of a calculated estimate on the right side of the equation yields to a more accurate estimate than equation (11) even if the rated values are slightly incorrect.

[0036] The calculation of the rotor time constant from equations (11) or (15) requires that both stator and rotor resistances are known. Stator resistance can be measured quite accurately during DC magnetization, but the rotor resistance estimate may have considerable errors due to the used injected signal and its frequency. Errors are caused especially by skin effect and inaccuracies in the voltage measurement and/or voltage control. Errors can also be due inaccuracies in determining the time instant t_z since the derivate of stator current is close to zero in the vicinity of i_{sdz_max}.

[0037] The sensitivity of estimates from equations (11) and (15) can be reduced by repeating the pulse test performed above with differing delays in using the zero vectors t_{z01} and t_{z02} This procedure is illustrated in Figure 3. Thus, two different tests are carried out, in which the machine is first magnetized with current i_{dc_magn} and the pulses are passivated at the time instant t_0. In test 1 the zero vector is taken into use at the time instant t_{z01}, after which the stator current flows according to curve i_{sd1} and reaches its maximum value i_{sdz_max1} at the time instant t_{z1}. In test 2 the zero vector is activated at a time instant which is after t_{z01}, i.e. at the time instant t_{z02}, after which the current flows according to curve i_{sd2} and reaches the maximum i_{sdz_max2} at the time instant t_{z2}.

[0038] According to equation (9) the rotor fluxes at the time instants t_{z1} and t_{z2} are

$$\begin{cases} \psi_R(t_{z1}) = \left(u_{th} + (R_s + R_R) i_{sdz_max1}\right)\tau_r \\ \psi_R(t_{z2}) = \left(u_{th} + (R_s + R_R) i_{sdz_max2}\right)\tau_r \end{cases} \quad (16)$$

[0039] If the zero vector was not switched on during time period $t_{z1} \cdots t_{z2}$, the rotor flux would decay, when the pulses are passivated, according to the exponential law of equation (10) such that:

$$\psi_R(t_{z2}) = \psi_R(t_{z1}) e^{-(t_{z2}-t_{z1})/\tau_r} \quad (17)$$

[0040] The rotor time constant can now be solved by making the same approximations as in the case with the estimate of equation (11), assuming that the increase of stator current during the zero vector does not considerably slow down the decaying of the rotor flux prior to the time instants t_{z1} and t_{z2} In other words, the decaying of the rotor flux (17) according to the exponential law satisfies the system of equations (16), whereby

$$\left(u_{th} + \left(R_s + R_R\right)i_{sdz_\max 2}\right)\tau_r = \left(u_{th} + \left(R_s + R_R\right)i_{sdz_\max 1}\right)\tau_r e^{-(t_{z2}-t_{z1})/\tau_r}$$

$$e^{-(t_{z2}-t_{z1})/\tau_r} = \frac{u_{th} + \left(R_s + R_R\right)i_{sdz_\max 2}}{u_{th} + \left(R_s + R_R\right)i_{sdz_\max 1}}$$

$$\Rightarrow \tau_r = \frac{t_{z2} - t_{z1}}{\ln\left(\frac{u_{th} + \left(R_s + R_R\right)i_{sdz_\max 1}}{u_{th} + \left(R_s + R_R\right)i_{sdz_\max 2}}\right)} \qquad (18)$$

[0041] By comparing equations (11) and (18) it is seen that the rotor time constant estimate calculated with equation (18) is considerably less dependent on the errors of the resistances than the estimate from equation (11). This sensitivity to errors in the resistance estimates decreases as the threshold voltage u_{th} decreases. Further, in equation (18) the relative effect of the zero vector on the decaying of the rotor flux is approximately equal in magnitude in both of the rotor fluxes calculated according to the system of equations (16). This means that the mentioned effect is practically compensated in the quotient of the logarithmic function of equation (18). Thus, when the rotor time constant is calculated using two separate zero vector tests, the effect of the zero vector need not to be taken into account like in connection with equation (15).

[0042] Further, the inaccuracy of determining the time instant t_z in the estimates from equations (11) and (15) can be avoided in the case of an estimate from equation (18). This is due to the fact that the rise times of the current (t_{z1}-t_{z01} and t_{z2}-t_{z02}) are practically the same. Thus, the time difference t_{z2} - t_{z1} in equation (18) can be replaced with the time difference t_{z02} - t_{z01}- Since the latter of the time differences is a precisely known estimate,

$$\tau_r = \frac{t_{z02} - t_{z01}}{\ln\left(\frac{u_{th} + \left(R_s + R_R\right)i_{sdz_\max 1}}{u_{th} + \left(R_s + R_R\right)i_{sdz_\max 2}}\right)} \qquad (19)$$

gives even more precise results than the estimate from equation (18).

[0043] Thus, according to the present invention stator current is measured during the zero voltage vector and parameters of the induction machine are determined from the measured stator current.

[0044] In the above described embodiment, the determined parameter is a rotor time constant, and during the zero vector the maximum current and its time instant are also determined for the calculations.

[0045] According to an embodiment of the invention, after the first test procedure, the induction machine is magnetized again and the test procedure is repeated with a differing time period between the shut-down of the inverter and switching-on of the zero vector. The time difference between the time instants at which the currents reach their maximum is used for estimating the rotor time constant. In a preferred embodiment of the invention in which two separate tests are carried out, the time difference between the zero vector switching instants are used instead of the time difference between the highest current instants. As it is understood, by time differences between two separate measurements it is referred to

time instants measured from the beginning of the respective tests and not to time elapsed between tests.

Rotor resistance and threshold voltages

[0046] In the above-explained embodiment of the present invention, the rotor time constant was estimated. In the estimation, the used parameters included rotor resistance and threshold voltage. These parameters can be given for the estimation of the rotor time constant without using the present invention. However, the present invention provides a way to determine the rotor resistance R_R and the threshold voltage u_{th} more accurately than in previously known methods.

[0047] Assume that the machine has been magnetized with a current i_{dc_magn} until a steady state is obtained. After the magnetization the pulses are taken away, i.e. the power stage is passivated for a while and a zero vector is switched on at a time instant t_{z1}, where the current has fallen to a value i_{sd1}, as seen in Figure 4. Due to the zero vector, the collapsing of the stator current first stops and then the current decays slowly towards zero. In some cases, like in Figure 4, the current temporarily grows, forming a local maximum before it starts to decrease.

[0048] From equation (3) it follows that during the zero vector the derivative of the current is

$$\frac{di_{sd}}{dt} = \frac{1}{\sigma L_s}\left(\frac{\psi_R}{\tau_r} - u_{th} - (R_s + R_R)i_{sd}\right) \tag{20}$$

[0049] The objective is to find a limit value i_{sd0} for the stator current and a corresponding switching-on time instant t_{z0} for the zero vector such that the right-hand derivative of the stator current is zero at the time instant t_{z0}, i.e.

$$\lim_{t \to t_{z0}^+}\left(\frac{di_{sd}}{dt}\right) = \left(\frac{di_{sd}}{dt}\right)_{t=t_{z0}^+} = 0 .$$

[0050] Then, immediately after the turn-on instant of the zero vector the following holds:

$$\left(\frac{di_{sd}}{dt}\right)_{t=t_{z0}^+} = \frac{1}{\sigma L_s}\left(\frac{\psi_R(t_{z0})}{\tau_r} - u_{th} - (R_s + R_R)i_{sd0}\right) = 0 . \tag{21}$$

[0051] Since the rotor flux does not practically change when the current drops from i_{dc_magn} to i_{sd0}, the following approximation holds:

$$\psi_R(t_{z0}) \approx L_M i_{dc_magn} = \tau_r R_R i_{dc_magn} . \tag{22}$$

[0052] By inserting equation (22) into equation (21) we obtain

$$R_R i_{dc_magn} - u_{th} - (R_s + R_R)i_{sd0} = 0 . \tag{23}$$

[0053] In other words, the magnitude of the current limit i_{sd0} which produces a zero derivative of the current at the

time instant t_{z0} is

$$i_{sd0} = \frac{R_R i_{dc_magn} - u_{th}}{R_s + R_R}. \quad (24)$$

[0054] If the current falls below this limit prior to activating of the zero vector, the derivative corresponding to equation (21) is positive like in Figure 4, where t = t_{z1}. If again the zero voltage vector is activated as in Figure 5, i.e. too early, the current at the switching instant is $i_{sd2} > i_{sd0}$ and the derivative of the current is negative.

[0055] If the zero voltage vector is switched on at the time instant t_{z0}, where the current has dropped exactly to a value given by equation (24), the derivative of the stator current at the switching instant is zero and the current waveform is in accordance with Figure 6.

[0056] The aim is thus to find a current limit i_{sd0} which produces the current waveform of Figure 6. Practically multiple current tests have to be carried out for finding the correct current value. Between the tests the zero vector switching instant can be varied. Alternatively, the zero vector may be taken into use when the stator current drops to a set limit. This limit may also be varied for obtaining the correct current value, the derivative of which is zero at the turn-on instant.

[0057] Instead of passivating the power stage after the magnetization, the power stage can also be forced to produce a voltage vector with an opposing direction to that used during the DC magnetization, if the switching-on time instant of the zero voltage vector can be set more precisely.

[0058] The limit value for the current producing zero derivative at the switching-on time instant can be searched relatively fast. The magnetization of the machine for the next test can be started immediately after the current derivative at the beginning of the zero vector is calculated. The magnetization times between the tests are also quite short since the rotor flux does not decay much during the zero vectors. A typical stator current waveform during the search of the zero derivative is shown in Figure 7.

[0059] Alternatively, the current limit i_{sd0} can be approximated from two current responses giving a positive derivative and negative derivative. If these current responses are like in Figures 4 and 5, the approximation of the current limit can be calculated from current limits i_{sd1} and i_{sd2} by weighting them in proportion to the derivatives, for example in the following way:

$$i_{sd0} \approx \frac{i_{sd2}\left|\left(\frac{di_{sd}}{dt}\right)_{t=t_{z1}^{+}}\right| + i_{sd1}\left|\left(\frac{di_{sd}}{dt}\right)_{t=t_{z2}^{+}}\right|}{\left|\left(\frac{di_{sd}}{dt}\right)_{t=t_{z1}^{+}}\right| + \left|\left(\frac{di_{sd}}{dt}\right)_{t=t_{z2}^{+}}\right|}. \quad (25)$$

[0060] When the optimum current response and the related current limit i_{sd0} are found, the rotor resistance estimate can be calculated using the current limit from equation (23), giving:

$$R_R = \frac{u_{th} + R_s i_{sd0}}{i_{dc_magn} - i_{sd0}} \quad (26)$$

[0061] The calculation of rotor resistance requires that the threshold voltage u_{th} and the stator resistance R_S are known. The problem of equation (26) is that the value of the threshold voltage is not necessarily known accurately. Further, the value of the threshold voltage affects the accuracy of the estimate obtainable with equation (26) greatly. If, however, the threshold voltage is known, equation (26) can be used directly.

[0062] Typically in frequency converters, the threshold voltage is a parameter set to a constant value or estimated during DC magnetization. If the threshold voltage is estimated, the commutation delays in the power stage make the

threshold voltage estimate less accurate and also thus the estimate of rotor resistance if the threshold voltage u_{th} obtained from DC magnetization is placed to equation (26).

[0063] Equation (23) can, however, be used for obtaining a more accurate value for the threshold voltage (or for eliminating the threshold voltage). In a situation where the equation (23) holds, a zero vector is activated, current is even and it flows via the power components whose threshold voltage should be known in the above equations.

[0064] The idea behind this estimation is to carry out multiple zero vector tests described above with differing DC magnetization currents before passivating the power stage and by searching for different magnetizing currents $i_{dc_magn,\,i}$ respective current limits $i_{sd0,1}$ which produce a zero derivative of the current at the instant of switching-on of the zero vector. Equation (23) holds then regardless of the magnitude of the used magnetizing current.

[0065] For example, by using two different magnetizing currents we obtain a pair of equations:

$$\begin{cases} R_R i_{dc_magn,1} = u_{th} + (R_s + R_R) i_{sd0,1} \\ R_R i_{dc_magn,2} = u_{th} + (R_s + R_R) i_{sd0,2} \end{cases} \tag{27}$$

and by eliminating the threshold voltage u_{th}, the rotor resistance can be calculated as a function of stator resistance:

$$R_R = \frac{i_{sd0,1} - i_{sd0,2}}{(i_{dc_magn,1} - i_{dc_magn,2}) - (i_{sd0,1} - i_{sd0,2})} R_s \tag{28}$$

[0066] The threshold voltage can also be solved from the pair of equations (27), giving:

$$u_{th} = \frac{(i_{dc_magn,1} - i_{sd0,1}) i_{sd0,2} - (i_{dc_magn,2} - i_{sd0,2}) i_{sd0,1}}{(i_{dc_magn,2} - i_{sd0,2}) - (i_{dc_magn,1} - i_{sd0,1})} R_s \tag{29}$$

[0067] Correspondingly by using multiple different DC magnetizing currents we end in a group of equations

$$\begin{cases} i_{dc_magn,1} = A + B i_{sd0,1} \\ i_{dc_magn,2} = A + B i_{sd0,2} \\ \dots \\ i_{dc_magn,n} = A + B i_{sd0,n} \end{cases} \tag{30}$$

[0068] By using linear regression, the regression coefficients proportional to the threshold voltage and to the resistance ratio can be calculated

$$\begin{cases} A \approx \dfrac{u_{th}}{R_R} \\ B \approx \dfrac{R_s + R_R}{R_R} \end{cases} \tag{31}$$

and further, the rotor resistance estimate and threshold voltage estimate can be calculated as a function of stator resistance.

$$\begin{cases} R_R = \dfrac{R_s}{(B-1)} \\ u_{th} = \dfrac{AR_s}{(B-1)} \end{cases} \tag{32}$$

[0069] Since the measurements are carried out with multiple measurement points, the estimates obtained with (32) are basically more accurate than the ones obtained with equations (28) and (29).

[0070] The estimated threshold voltage and rotor resistance can be identified separately and these estimates need not be used in the embodiment given above.

Parameter-independent rotor time constant

[0071] In the above-described embodiments of estimating the rotor time constant, the sum of stator and rotor resistances was assumed to be known (equations (11), (15), (18) and (19)). Further equations (11) and (15) require the rotor resistance as a separate parameter. When rotor resistance and threshold voltage estimates obtained with the above embodiments of the invention or in some other way are placed to the above mentioned equations, the stator resistance is still an unknown parameter. Stator resistance can be easily measured during DC magnetization as a ratio between voltage and current. However, the stator resistance measured in this way has a certain uncertainty since typically the average output voltage of a frequency converter is determined from the DC voltage of the intermediate circuit and from the output switch combination.

[0072] Due to commutation delays and uncertainties of compensation of the threshold voltages of the power stage, the output voltage of the frequency converter may be slightly inaccurate. This inaccuracy has a major impact during the DC magnetization since the voltage fed to the machine is small. This can be seen as an error in the stator resistance identified during the DC magnetization and further in the rotor time constant if it is calculated based on the stator resistance.

[0073] The rotor time constant can be calculated almost independently of any parameters, when above mentioned embodiments of estimating the rotor time constant, the rotor resistance and the threshold voltage are combined. In this embodiment of the invention two separate zero vector tests are carried out. In the first test (Figure 8, test 1) the machine is magnetized with a current i_{dc_magn1} until a steady state is obtained. The pulses are then removed at a time instant t_0 and a zero vector is started at a time instant t_{z0}. Due to the zero vector the current starts to increase and reaches a local maximum i_{sdz_max} at a time instant t_z.

[0074] After the first test, a second phase of the embodiment is carried out. In the second phase (test 2) a similar zero vector test is carried out as in connection with the embodiment used for determining the rotor time constant and threshold voltage. In this case the machine is magnetized using DC current i_{dc_magn2}, after which the pulses are removed (the power stage is passivated) at the time instant t_0. When the current has dropped to the level of the local maximum i_{sdz_max} obtained in test 1, a zero vector is activated. The purpose of test 2 is to find a magnetizing current i_{dc_magn2} that causes the current response to have a zero derivative when machine is magnetized with the mentioned current and the zero vector is activated when the current is at the level of the mentioned local maximum.

[0075] The suitable magnetizing current can be searched by using the above described method for finding the zero derivative (Figures 4 to 7) such that i_{sd0} is replaced by i_{sdz_max}. In this case, however, the magnetizing current is changed instead of the current limit i_{sd0}. For example in the case of Figure 4 the magnetizing current should be reduced, and in the case of Figure 5 the magnetizing current should be increased.

[0076] When the magnetizing current producing the zero derivative of the stator current has been found, according to equation (23)

$$R_R i_{dc_magn2} = u_{th} + (R_s + R_R) i_{sdz_max}. \quad (33)$$

[0077] When equation (33) is inserted into equation (11) (such that i_{dc_magn} is substituted with i_{dc_magn1}), we obtain an estimate for the rotor time constant:

$$\Rightarrow \tau_r = \frac{t_z - t_0}{\ln\left(\frac{i_{dc_magn1}}{i_{dc_magn2}}\right)}. \quad (34)$$

[0078] As seen, in the formula according to equation (34) no motor parameters need to be known. The formula contains a small error, since, like equation (11), equation (34) does not take into account the increase of stator current in the decaying of the rotor flux during time period t_{z0}... t_z. This error depends on the motor parameters and, in this sense, equation (34) is not completely independent of the parameters of the machine.

[0079] A more accurate estimate, which takes into account the increase of stator current during period t_{z0}... t_z, was introduced in equation (15). The same equation can also be used in connection with the present embodiment. When equation (33) is inserted into equation (15), we obtain:

$$\Rightarrow \tau_r = \frac{t_{z0} - t_0}{\ln\left(\frac{\tau_r i_{dc_magn1}}{i_{dc_magn2}(\tau_r + t_z - t_{z0}) - \int_{t_{z0}}^{t_z} i_{sd}(t)dt}\right)} \quad (35)$$

[0080] Like equation (34), equation (35) does not require any machine parameters. By using equation (35) a more accurate estimate of the rotor time constant can be obtained. On the other hand, the problem relating to equation (35) is that the rotor time constant is present in implicit form and to solve it requires iteration. The equation is, however, easily solved with an iteration algorithm by always inserting the previously calculated estimate into the logarithmic function on the right-hand side of the equation. The iteration converges quite rapidly since the right-hand side of the equation is not very heavily dependent on the rotor time constant used in the arguments of the logarithmic function.

[0081] In theory, the estimate produced by equation (35) is completely independent of other machine parameters if the L-equivalent circuit represents the dynamics of the machine accurately. In practice, the effect of iron losses on the derivative of current at the time instant t_0 is considerable and thus the magnetizing current i_{dc_magn2} giving the zero derivative can be something else than what it should be when it is calculated using the parameters of the L-equivalent circuit.

[0082] For this reason it is advisable to carry out two zero vector tests, prior to which the pulses are passivated for a certain period of time such that current is always zero when the zero vectors are activated, as indicated in Figure 9. These tests are basically similar to the ones in Figure 3. However, in this case the idea is to use two different magnetizing currents, i_{dc_magn1} and i_{dc_magn2}, in such a way that the maximum values of the stator currents during the zero vectors are equal in magnitude. In other words, in Figure 9 $i_{sdz_max1} = i_{sdz_max2} = i_{sdz_max}$. Since in the situation of Figure 9 $t_{z02} > t_{z01}$, in test 2 the magnetizing current i_{dc_magn2} has to be higher than the magnetizing current i_{dc_magn1} so that the decaying of the rotor flux during time interval $t_{z01} \cdots t_{z02}$ would be compensated.

[0083] By assuming that the rotor flux decays according to the same exponential law from time instant t_0 to instants

t_{z1} and $t_{z2,}$ based on equation (12), we obtain

$$\begin{cases} L_M i_{dc_magn1} e^{-(t_{z1}-t_0)/\tau_r} = \left(u_{th} + \left(R_s + R_R\right) i_{sdz_\max}\right)\tau_r - R_R \int_{t_{z01}}^{t_{z1}} i_{sd1}(t)dt \\ L_M i_{dc_magn2} e^{-(t_{z2}-t_0)/\tau_r} = \left(u_{th} + \left(R_s + R_R\right) i_{sdz_\max}\right)\tau_r - R_R \int_{t_{z02}}^{t_{z2}} i_{sd2}(t)dt \end{cases} \quad (36)$$

[0084] The current pulses during the zero vectors are identical, and thus

$$\int_{t_{z01}}^{t_{z1}} i_{sd1}(t)dt = \int_{t_{z02}}^{t_{z2}} i_{sd2}(t)dt$$

[0085] The right-hand sides of the equation pair (36) have the same magnitude, and we obtain

$$L_M i_{dc_magn1} e^{-(t_{z1}-t_0)/\tau_r} = L_M i_{dc_magn2} e^{-(t_{z2}-t_0)/\tau_r} \quad (37)$$

[0086] If the main inductance is not saturated when the magnetizing current increases *from* i_{dc_magn1} to i_{dc_magn2}, it will be reduced from equation (37), leaving the rotor time constant as the only unknown.

[0087] From equation (37) the rotor time constant can be solved as follows:

$$i_{dc_magn1} e^{-(t_{z1}-t_0)/\tau_r} = i_{dc_magn2} e^{-(t_{z2}-t_0)/\tau_r}$$

$$\Leftrightarrow e^{(t_{z2}-t_{z1})/\tau_r} = \frac{i_{dc_magn2}}{i_{dc_magn1}}$$

$$\Leftrightarrow \tau_r = \frac{t_{z2}-t_{z1}}{\ln\left(\frac{i_{dc_magn2}}{i_{dc_magn1}}\right)} \quad (38)$$

[0088] Thus, in the preferred embodiment the machine is first magnetized with a magnetizing current i_{dc_magn1}. After the magnetization the switches of the inverter are controlled to non-conductive state at the time instant t_0. At the time instant t_{z01} the inverter is controlled to produce a zero vector and stator current starts to rise. At the time instant t_{z1} stator current reaches its maximum value i_{sdz_max1} and starts to decay.

[0089] The machine is magnetized again using a different magnetization current i_{dc_magn2} and a similar procedure is repeated. The intention is to find a magnetizing current and a corresponding time instant when the zero vector is taken into use, which produce a stator current having a maximum value which corresponds to that obtained in the first phase of the test.

[0090] It is possible that the desired magnetizing current has to be searched by repeating the second phase of the test. The maximum value of the stator current during the zero vector can be changed by varying the magnitude of the

magnetizing current or the time instant when the zero vector is taken into use. In Figure 9 it is shown that the second magnetizing current i_{dc_magn2} is higher than the first one i_{dc_magn1}. However, the operation of the embodiment does not require that the lower current is used first. The only requirement for the currents is that the currents have different magnitudes.

[0091] Once the second magnetizing current and the time instant of the maximum value of the stator current during the zero vector have been found, the rotor time constant can be calculated using equation (38), in which also the magnitude of the magnetizing current of the first magnetization and the time instant of the maximum value of the stator current during the first phase are used.

[0092] Since the current pulses during the zero vectors are identical,

$$t_{z1} - t_{z01} = t_{z2} - t_{z02}$$

holds. Thus in equation (38), the time difference t_{z02} - t_{z01} can be used instead of the time difference t_{z2} - t_{z1}, resulting in

$$\tau_r = \frac{t_{z02} - t_{z01}}{\ln\left(\frac{i_{dc_magn2}}{i_{dc_magn1}}\right)}. \qquad (39)$$

[0093] Since the time difference between the turn-on instants of the zero vectors can be determined more accurately than the time difference between the maximum currents, the estimate of the rotor time constant from equation (39) gives more accurate results than equation (38).

[0094] Equation (39) can also be reached in a more straightforward manner by concluding that the rotor flux Ψ_{R2} in the last test at the time instant $t_0 + t_{z02} - t_{z01}$ must be equal to rotor flux Ψ_{R1} at the time instant t_0 in the first test. This is due to the fact that the zero vectors are switched on after an equal time period (= t_{z01}) has expired after these instants, and they produce current pulses with exactly the same magnitude.

[0095] Thus, it can be concluded that the following holds and leads directly to equation (39)

$$\psi_{R1}(t_0) = \psi_{R2}(t_0 + t_{z02} - t_{z01}) = \psi_{R2}(t_0)e^{-(t_{z02}-t_{z01})/\tau_r}$$

$$\Leftrightarrow L_M i_{dc_magn1} = L_M i_{dc_magn2} e^{-(t_{z02}-t_{z01})/\tau_r} \qquad (40)$$

$$\Rightarrow \text{equation (39).}$$

Main inductance

[0096] The main inductance L_M can be calculated from the estimates obtained with the embodiments of the present invention as a product of rotor time constant and rotor resistance, i.e.

$$L_M = R_R \tau_r \qquad (41)$$

[0097] The main inductance calculated with equation (41) is accurate since the rotor time constant and the rotor resistance estimated with the method of the invention are also accurate.

Control system

[0098] Figure 10 shows an example of a control system that is usable to carry out the method of the invention. The control system is used during normal operation of a frequency converter for controlling the machine in a desired manner. The control system produces control signals to the power stage of the frequency converter. The control signals are calculated in a modulator of the frequency converter according to a modulation scheme with which the machine is controlled.

[0099] In Figure 10 the control system contains a current controller, a voltage controller and a modulator operating in a dq-coordinate system. During DC magnetization the voltage reference is outputted by the current controller, which controls the d-component of the current according to the reference for the magnetizing current $i_{dc...magn}$ and, correspondingly, controls the q-component of the current to zero. With these control actions the current vector is forced in the direction of an angle θ, which gives the direction of the magnetization and thus the direction of the d-axis. The voltage reference is transformed into the stator reference frame and fed to the voltage controller and further to the modulator controlling the power stage. The induction machine connected to the frequency converter produces a current response, which is transformed into the dq-coordinate system on the basis of the measured phase currents and the direction of the magnetization theta. Preferably the angle θ is selected to be in the direction of a phase of the induction machine, but, it can also be selected arbitrarily.

[0100] The control system can be used in connection with determining the rotor time constant described above in the following way. At the time instant t = t_0 (see Figure 2), the identification block passivates the power stage of the frequency converter by setting parameter mod_ena to False, which sets the output switch components to off-state and phase currents to zero when the terminal voltage of the machine sets to the voltage induced by the decaying rotor flux. At the time instant t = t_{z0} the identification block activates the power stage and forces a zero voltage vector to use by setting both parameters mod_ena and zero_force to True. During the zero voltage vector the identification block determines the maximum value of current i_{sd} (i_{sdz_max}) and its time instant t_z for determining the rotor time constant according to equation (11).

[0101] The other embodiments of the invention can be carried out similarly with the control system of Figure 10 by sequentially controlling the enable signals zero_force and mod_ena. The signal zero_force forces the zero vector to be taken into use (time instants t_{z0}, t_{z01} and t_{z02}) and the signal mod_ena passivates the power stage (time instant t_0). In the example of Figure 10 the zero vector is commanded by giving a voltage reference to the modulator. The zero vector can alternatively be taken into use by controlling the output switch components directly without using the voltage reference illustrated in Figure 10.

[0102] Different embodiments of the invention may require a different number of DC magnetizations, power stage passivations and zero vector forcings, as was described above in detail in connection with the different embodiments. An identification logic block in Figure 10 takes care of the various signals controlling the procedures of the invention and also monitors the magnitude of the stator current and its derivative for obtaining values for i_{sdz_max}, i_{sdz_max1}, i_{sdz_max2}, i_{sd0} , t_z, t_{z1} and t_{z2}. These values are signalled to a parameter calculation block, which uses various equations for calculating the required parameters as described above in detail.

[0103] The above control system indicates that all above described parameters are calculated. However, some of the parameters need not be estimated using the method of the invention and some of the parameters may be estimated using other methods.

[0104] It will be obvious to a person skilled in the art that, as the technology advances, the inventive concept can be implemented in various ways. The invention and its embodiments are not limited to the examples described above but may vary within the scope of the claims.

Claims

1. Method of identifying parameters of an induction machine when the induction machine is connected to the output phases of a voltage source inverter and the induction machine is in standstill state, **characterized by**
   providing DC magnetization current (i_{dc_magn}) to the induction machine with the inverter, until the flux of the machine reaches steady state,
   then, controlling the power semiconductors of the inverter to off-state for a certain time interval (t0-tz0),
   und then, controlling all output phases of the inverter to the same potential for providing a zero voltage vector,
   measuring the stator current (i_{sd}) during the zero voltage vector, and
   determining parameters of the induction machine from the stator current (i_{sd}) measured during the zero voltage vector.

2. Method according to claim 1, **characterized in that** the identified parameter is a rotor time constant (τ_r), wherein the measuring of the stator current (i_{sd}) comprises the step of measuring the maximum current (i_{sd_max}) during the

zero voltage vector and its time instant (t_z),
determining the rotor time constant (τ_r) from
the magnitude of the DC magnetization current (i_{dc_magn}),
stator and rotor resistances (R_S, R_R) of the machine,
the determined maximum current (i_{sdz_max}) and its time instant (t_z),
the time instant (t_0) when the power semiconductors are controlled to off-state, and
from the threshold voltage of the inverter (u_{th}).

3. Method according to claim 1,**characterized in that** the identified parameter is a rotor time constant (τ_r), wherein the measuring of the stator current comprises the step of measuring the maximum current (i_{sdz_max}) during the zero voltage vector and its time instant (t_z),
determining the rotor time constant numerically using an iteration algorithm from
the magnitude of the DC magnetization current (i_{dc_magn}),
stator and rotor resistances (R_S, R_R) of the machine,
the determined maximum current (i_{sdz_max}) and its time instant (t_z),
the time instant (t_{z0}) when the zero vector is taken into use,
the time instant (t_0) when the power semiconductors are controlled to off-state,
the threshold voltage (u_{th}) of the inverter, and
from an initial estimate of the rotor time constant.

4. Method according to claim 1, **characterized in that** the identified parameter is a rotor time constant (τ_r), wherein the measurement of the stator current comprises measurement of the maximum (i_{sdz_max}) current and its time instant (t_z),
the measurement of the maximum current is repeated using the same magnetization current (i_{dc_magn}) with different turn-on instants (t_{z01}, t_{z02}) for the zero voltage vector
determining the rotor time constant from
the measured time instants (t_{z1}, t_{z2}) of the maximum currents,
the measured maximum currents (i_{sdz_max1}, i_{sdz_max2}),
stator and rotor resistances (R_S, R_R) of the machine, and
the threshold voltage (u_{th}) of the inverter.

5. Method according to claim 1, **characterized in that** the identified parameter is a rotor time constant (τ_r), wherein the measurement of the stator current comprises measurement of the maximum current (i_{sdz_max}).
the measurement of the maximum current is repeated using the same magnetization current (i_{dc_magn}) with different turn-on instants (t_{z01}, t_{z02}) for the zero voltage vector,
determining the rotor time constant from
the turn-on time instants (t_{z01}, t_{z02}) for zero voltage vectors,
the measured maximum currents (i_{sdz_max1}, i_{sdz_max2}),
stator and rotor resistances (R_S, R_R) and
the threshold voltage (u_{th}) of the inverter.

6. Method according to claim 1, **characterized in that** the identified parameter is rotor resistance (R_R) of the machine, wherein
controlling the output phases of the inverter to the same potential comprises a step in which the output phases are controlled to the same potential such that the derivative of the stator current (i_{sd}) immediately after the switching is zero, and
measuring the stator current (i_{sd}) comprises a step in which the stator current is measured immediately after the switching, wherein the rotor resistance (R_R) is calculated from
the measured stator current (i_{sd0}),
the magnitude of the magnetization current (i_{dc_magn}),
the threshold voltage (u_{th}) of the inverter, and
stator resistance (R_S) of the machine.

7. Method according to claim 1, **characterized in that** the identified parameter is rotor resistance (R_R) of the machine, wherein
controlling the output phases to the same potential comprises a step in which the output phases are controlled to the same potential such that the derivative of the stator current (i_{sd}) immediately after the switching is zero,
measuring the stator current comprises a step in which the stator current is measured immediately after the switching,

and
the steps are repeated with different magnetization currents ($i_{dc_magn,1}$, $i_{dc_magn,2}$, $i_{dc_magn,n}$) once or multiple of times for obtaining two or more stator current values ($i_{sd0,1}$, $i_{sd0,2}$, $i_{sd0,n}$) and magnitudes of magnetization currents ($i_{dc_magn,1}$, $i_{dc_mag,2}$, $i_{dc_magn,n}$),
wherein the rotor resistance is calculated from
the measured stator currents ($i_{sd0,1}$, $i_{sd0,2}$, $i_{sd0,n}$),
the magnitudes of the magnetization currents ($i_{dc_magn,1}$, $i_{dc_magn,2}$, $i_{dc_magn,n}$), and
stator resistance (R_S) of the machine.

8. Method according to claim 1, **characterized in that** the identified parameter is a threshold voltage (u_{th}) of the inverter, wherein
controlling the output phases to the same potential comprises a step in which the output phases are controlled to the same potential such that the derivative of the stator current instantly after the switching is zero, and
measuring the stator current comprises a step in which the stator current is measured instantly after the switching,
wherein the threshold voltage of the inverter is calculated from
the measured stator current (i_{sd0}),
the magnitude of the magnetization current (i_{dc_magn}),
rotor resistance (R_R) of the machine, and
stator resistance (R_S) of the machine.

9. Method according to claim 1, **characterized in that** the identified parameter is a threshold voltage (u_{th}) of the inverter, wherein
controlling the output phases to the same potential comprises a step in which the output phases are controlled to the same potential such that the derivative of the stator current instantly after the switching is zero,
measuring the stator current comprises a step in which the stator current is measured instantly after the switching, and
the steps are repeated with different magnetization currents once or multiple times for obtaining two or more stator current values ($i_{sd0,1}$, $i_{sd0,2}$, $i_{sd0,n}$) and magnitudes of magnetization currents ($i_{dc_magn,1}$, $i_{dc_magn,2}$, $i_{dc_magn,n}$),
wherein the threshold voltage of the inverter is calculated from
the measured stator currents ($i_{sd0,1}$, $i_{sd0,2}$, $i_{sd0,n}$),
the magnitudes of the magnetization currents ($i_{dc_magn,1}$, $i_{dc_magn,2}$, $i_{dc_magn,n}$), and
stator resistance (R_S) of the machine.

10. Method according to claim 1, **characterized in that** the identified parameter is a rotor time constant, wherein
the measuring comprises the step of measuring the maximum current (i_{sdz_max}) during the zero voltage vector and its time instant (t_z),
the method further comprising the steps of

a) providing DC magnetization to the induction machine with a second magnetization current,
b) controlling the power semiconductors of the inverter to off-state,
c) controlling all output phases of the inverter to the same potential for providing a zero voltage vector when the stator current has dropped to the value of the measured maximum current (i_{sdz_max}), and determining the derivative of the stator current instantly after the controlling of the output switches,

changing the value of the second magnetizing current ($i_{dc_magn,2}$) and repeating the above steps a), b) and c) if the determined derivative of the stator current is not zero,
calculating the rotor time constant from
the time instant (t_z) of the maximum current (i_{sdz_max}) of the stator current during the zero vector,
the time instant (t_0) when the power semiconductors are controlled to off-state,
the magnitude of the magnetizing current ($i_{dc_magn,1}$) used in the magnetization that produced the measured maximum current (i_{sdz_max}), and
the magnitude of the second magnetizing current ($i_{dc_magn,2}$) that produced the zero derivative of the stator current.

11. Method according to claim 1, **characterized in that** the identified parameter is a rotor time constant, wherein
the measuring comprises the step of measuring the maximum current (i_{sdz_max}) during the zero voltage vector and its time instant (t_z),
the method further comprising the steps of

a) providing DC magnetization to the induction machine with a second magnetization current,

b) controlling the power semiconductors of the inverter to off-state,
c) controlling all output phases of the inverter to the same potential for providing a zero voltage vector when the stator current has dropped to the value of the measured maximum current, and determining the derivative of the stator current instantly after the controlling of the output switches,

changing the value of the second magnetizing current ($i_{dc_magn,2}$) and repeating the above steps a), b) and c) if the determined derivative of the stator current is not zero,
calculating the rotor time constant from
the turn-on time instant (t_{z0}) when the zero voltage vector is activated,
the time instant (t_z) of the maximum current of the stator current during the zero vector,
the time instant (t_0) when the power semiconductors are controlled to off-state,
the magnitude of the magnetizing current ($i_{dc_magn,1}$) used in the magnetization that produced the measured maximum current (i_{sdz_max}),
the magnitude of the second magnetizing current ($i_{dc_magn,2}$) that produced the zero derivative of the stator current, and
an initial value of the rotor time constant.

12. Method according to claim 11, **characterized in that** the rotor time constant is calculated iteratively using the calculated rotor time constant as an initial value of the rotor time constant in the iteration.

13. Method according to any of the previous claims 1 to 12, **characterized in that** after the magnetization, instead of controlling the power semiconductors of the inverter to off-state, the power semiconductors are controlled to produce a voltage vector having an opposite polarity when compared to the voltage vector used in the magnetization.

14. Method according to claim 1, **characterized in that** the identified parameter is a rotor time constant, wherein
the measuring comprises the step of measuring the maximum current (i_{sdz_max}) during the zero voltage vector and its time instant (t_{z1}),
the method further comprising the steps of

a) providing DC magnetization to the induction machine with a second magnetization current ($i_{dc_magn,2}$),
b) controlling the power semiconductors of the inverter to off-state,
c) controlling all output phases of the inverter to the same potential for providing a zero voltage vector, and measuring the maximum value of the stator current during the zero voltage vector and its time instant (t_{z2}),

changing the value of the second magnetizing current ($i_{dc_magn,2}$) and repeating the above steps a), b) and c) if the maximum value of the stator current is not equal to the maximum current (i_{sdz_max}) measured during the first magnetization,
calculating the rotor time constant from
the time instant (t_{z1}, t_{z2}) of the maximum current (i_{sdz_max}) of the stator current during the zero vectors,
the magnitude of the magnetizing current ($i_{dc_magn,1}$) used in the magnetization that produced the measured maximum current (i_{sdz_max}), and
the magnitude of the second magnetizing current ($i_{dc_magn,2}$) that produced a stator current which had the maximum value equal to that of the first magnetization.

15. Method according to claim 14, **characterized in that**, in the calculation of the rotor time constant, the time instants (t_{z01}, t_{z02}) when the zero vectors were taken into use are used, instead of the time instants (t_{z1}, t_{z2}) of the maximum currents.

16. Method according to claim 14 or 15, **characterized in that** instead of changing the value of the magnetization current, the time instant when the zero vector is taken into use is changed for obtaining a stator current having a maximum value equal to that of the maximum current measured during the first magnetization.

17. An arrangement for identifying parameters of an induction machine when the induction machine is connected to the output phases of a voltage source inverter and the induction machine is in standstill state, **characterized by** means configured to :

provide DC magnetization ($_{idc\text{-}magn}$) to the induction machine with the inverter, untill the flux of the machine reaches steady state,

control the power semiconductors of the inverter to off-state for a certain time interval (t_0-t_{z0}) after the DC magnetization,
control all output phases of the inverter to the same potential for providing a zero voltage vector after the passivation of the inverter power stage, measure the stator current (isd) during the zero voltage vector application time, and
determine parameters of the induction machine from the stator current (isd) measured during the zero voltage vector.

Patentansprüche

1. Verfahren zum Identifizieren von Parametern einer Induktionsmaschine, wenn die Induktionsmaschine mit den Ausgangsphasen eines Spannungsquellenwechselrichters verbunden ist und die Induktionsmaschine im Stillstandszustand ist, **gekennzeichnet durch**
Bereitstellen von DC Magnetisierungsstrom (i_{dc_magn}) für die Induktionsmaschine mit dem Wechselrichter, bis der Fluss der Maschine einen stabilen Zustand erreicht,
dann Steuern der Leistungshalbleiter des Wechselrichters in den Aus-Zustand für ein bestimmtes Zeitintervall (t_0—t_{z0}),
und dann Steuern aller Ausgangsphasen des Wechselrichters auf das gleiche Potential um einen Null-Spannungs-Vektor bereitzustellen,
Messen des Statorstroms (i_{sd}) während des Null-Spannungs-Vektors, und
Bestimmen von Parametern der Induktionsmaschine aus dem während des Null-Spannungs-Vektors gemessenen Statorstrom (i_{sd}).

2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der identifizierte Parameter eine Rotorzeitkonstante (τ_r) ist, wobei
das Messen des Statorstroms (i_{sd}) den Schritt des Messens des maximalen Stroms (i_{sdz_max}) während dem Null-Spannungs-Vektor und dem Zeitpunkt (t_z) seines Vorliegens aufweist,
Bestimmen der Rotorzeitkonstante (τ_r) aus
der Größe des DC Magnetisierungsstroms (i_{dc_magn}),
Stator- und Rotorwiderständen (R_S, R_R) der Maschine,
dem bestimmten maximalen Strom (i_{sdz_max}) und dem Zeitpunkt (t_z) seines Vorliegens,
dem Zeitpunkt (t_0), zu dem die Leistungshalbleiter in den Aus-Zustand gesteuert werden, und
aus der Schwellwertspannung (u_{th}) des Wechselrichters.

3. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der identifizierte Parameter eine Rotorzeitkonstante (τ_r) ist, wobei
das Messen des Statorstroms den Schritt des Messens des maximalen Stroms (i_{sdz_max}) während dem Null-Spannungs-Vektor und dem Zeitpunkt (t_z) seines Vorliegens aufweist,
numerisches Bestimmen der Rotorzeitkonstante unter Verwendung eines Iterationsalgorithmus aus
der Größe des DC Magnetisierungsstroms (i_{dc_magn}),
Stator- und Rotorwiderständen (R_S, R_R) der Maschine,
dem bestimmten maximalen Strom (i_{sdz_max}) und dem Zeitpunkt (t_z) seines Vorliegens,
dem Zeitpunkt (t_{z0}), zu dem der Null-Vektor eingenommen wird,
dem Zeitpunkt (t_0), zu dem die Leistungshalbleiter in den Aus-Zustand gesteuert werden,
der Schwellwertspannung (u_{th}) des Wechselrichters, und
aus einer anfänglichen Schätzung der Rotorzeitkonstante.

4. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der identifizierte Parameter eine Rotorzeitkonstante (τ_r) ist, wobei
das Messen des Statorstroms den Schritt des Messens des maximalen Stroms (i_{sdz_max}) und den Zeitpunkt (t_z) seines Vorliegens aufweist,
das Messen des maximalen Stroms unter Verwendung des gleichen Magnetisierungsstroms (i_{dc_magn}) mit verschiedenen Einschaltzeitpunkten (t_{z01}, t_{z02}) für den Null-Spannungs-Vektor wiederholt wird
Bestimmen der Rotorzeitkonstante aus
den gemessenen Zeitpunkten (t_{z1}, t_{z2}) der maximalen Ströme,
den gemessenen maximalen Strömen (i_{sdz_max1}, i_{sdz_max2}),
Stator- und Rotorwiderständen (R_S, R_R) der Maschine, und

der Schwellwertspannung (u_{th}) des Wechselrichters.

5. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der identifizierte Parameter eine Rotorzeitkonstante (τ_r) ist, wobei
das Messen des Statorstroms den Schritt des Messens des maximalen Stroms (i_{sdz_max}) aufweist,
das Messen des maximalen Stroms unter Verwendung des gleichen Magnetisierungsstroms (i_{dc_magn}) mit verschiedenen Einschaltzeitpunkten (t_{z01}, t_{z02}) für den Null-Spannungs-Vektor wiederholt wird,
Bestimmen der Rotorzeitkonstante aus
den Einschaltzeitpunkten (t_{z01}, t_{z02}) für Null-Spannungs-Vektoren,
den gemessenen maximalen Strömen (i_{sdz_max1}, i_{sdz_max2}),
Stator- und Rotorwiderständen (R_S, R_R), und
der Schwellwertspannung (u_{th}) des Wechselrichters.

6. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der identifizierte Parameter ein Rotorwiderstand (R_R) der Maschine ist, wobei
das Steuern der Ausgangsphasen des Wechselrichters auf das gleiche Potential einen Schritt aufweist, in welchem die Ausgangsphasen auf das gleiche Potential gesteuert werden, so dass die Ableitung des Statorstroms (i_{sd}) unmittelbar nach dem Schalten null ist, und
das Messen des Statorstroms (i_{sd}) einen Schritt aufweist, in welchem der Statorstrom unmittelbar nach dem Schalten gemessen wird, wobei der Rotorwiderstand (R_R) berechnet wird aus
dem gemessenen Statorstrom (i_{sd0}),
der Größe des Magnetisierungsstroms (i_{dc_magn}),
der Schwellwertspannung (u_{th}) des Wechselrichters, und
dem Statorwiderstand (R_S) der Maschine.

7. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der identifizierte Parameter ein Rotorwiderstand (R_R) der Maschine ist, wobei
das Steuern der Ausgangsphasen auf das gleiche Potential einen Schritt aufweist, in welchem die Ausgangsphasen auf das gleiche Potential gesteuert werden, so dass die Ableitung des Statorstroms (i_{sd}) unmittelbar nach dem Schalten null ist, und
das Messen des Statorstroms einen Schritt aufweist, in welchem der Statorstrom unmittelbar nach dem Schalten gemessen wird, und
die Schritte mit verschiedenen Magnetisierungsströmen ($i_{dc_magn,1}$, $i_{dc_magn,2}$, $i_{dc_magn,n}$) ein einzelnes Mal oder mehrere Male wiederholt werden, um zwei oder mehrere Statorstromwerte ($i_{sd0,1}$, $i_{sd0,2}$, $i_{sd0,n}$) und Größen von Magnetisierungsströmen ($i_{dc_magn,1}$, $i_{dc_magn,2}$, $i_{dc_magn,n}$) zu erhalten,
wobei der Rotorwiderstand berechnet wird aus
den gemessenen Statorströmen ($i_{sd0,1}$, $i_{sd0,2}$, $i_{sd0,n}$),
den Größen der Magnetisierungsströme ($i_{dc_magn,1}$, $i_{dc_magn,2}$, $i_{dc_magn,n}$), und
dem Statorwiderstand (R_S) der Maschine.

8. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der identifizierte Parameter eine Schwellwertspannung (u_{th}) des Wechselrichters ist, wobei
das Steuern der Ausgangsphasen auf das gleiche Potential einen Schritt aufweist, in welchem die Ausgangsphasen auf das gleiche Potential gesteuert werden, so dass die Ableitung des Statorstroms sofort nach dem Schalten null ist, und
das Messen des Statorstroms einen Schritt aufweist, in welchem der Statorstrom sofort nach dem Schalten gemessen wird, wobei die Schwellwertspannung des Wechselrichters berechnet wird aus
dem gemessenen Statorstrom (i_{sd0}),
der Größe des Magnetisierungsstroms (i_{dc_magn}),
dem Rotorwiderstand (R_R) der Maschine, und
dem Statorwiderstand (R_S) der Maschine.

9. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der identifizierte Parameter eine Schwellwertspannung (u_{th}) des Wechselrichters ist, wobei
das Steuern der Ausgangsphasen auf das gleiche Potential einen Schritt aufweist, in welchem die Ausgangsphasen auf das gleiche Potential gesteuert werden, so dass die Ableitung des Statorstroms sofort nach dem Schalten null ist,
das Messen des Statorstroms einen Schritt aufweist, in welchem der Statorstrom sofort nach dem Schalten gemessen wird, und

die Schritte mit verschiedenen Magnetisierungsströmen ein einzelnes Mal oder mehrere Male wiederholt werden, um zwei oder mehrere Statorstromwerte ($i_{sd0,1}$, $i_{sd0,2}$, $i_{sd0,n}$) und Größen von Magnetisierungsströmen ($i_{dc_magn,1}$, $i_{dc_magn,2}$, $i_{dc_magn,n}$) zu erhalten,
wobei die Schwellwertspannung des Wechselrichters berechnet wird aus den gemessenen Statorströmen ($i_{sd0,1}$, $i_{sd0,2}$, $i_{sd0,n}$),
den Größen der Magnetisierungsströme ($i_{dc_magn,1}$, $i_{dc_magn,2}$, $i_{dc_magn,n}$), und dem Statorwiderstand (R_S) der Maschine.

10. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der identifizierte Parameter eine Rotorzeitkonstante ist, wobei
das Messen den Schritt des Messens des maximalen Stroms (i_{sdz_max}) während des Null-Spannungs-Vektors und dem Zeitpunkt (t_z) seines Vorliegens aufweist,
das Verfahren weiterhin die Schritte aufweist

a) Bereitstellen von DC-Magnetisierung an die Induktionsmaschine mit einem zweiten Magnetisierungsstrom,
b) Steuern der Leistungshalbleiter des Wechselrichters in den Aus-Zustand,
c) Steuern aller Ausgangsphasen des Wechselrichters auf das gleiche Potential um einen Null-Spannungs-Vektor bereitzustellen, wenn der Statorstrom auf den Wert des gemessenen maximalen Stroms (i_{sdz_max}) gesunken ist, und Bestimmen der Ableitung des Statorstroms sofort nach dem Steuern der Ausgangsschalter,

Wechseln des Wertes des zweiten Magnetisierungsstroms ($i_{dc_magn,\ 2}$) und Wiederholen der oben genannten Schritte a), b) und c) wenn die bestimmte Ableitung des Statorstroms nicht null ist,
Berechnen der Rotorzeitkonstante aus
dem Zeitpunkt (t_z) des maximalen Stroms (i_{sdz_max}) des Statorstroms während des Null-Vektors,
dem Zeitpunkt (t_0), zu dem die Leistungshalbleiter in den Aus-Zustand gesteuert werden,
der Größe des Magnetisierungsstroms ($i_{dc_magn,1}$), welcher für die Magnetisierung genutzt wurde, der den gemessenen maximalen Strom (i_{sdz_max}) geliefert hat, und
der Größe des zweiten Magnetisierungsstroms ($i_{dc_magn,2}$), welcher die Ableitung des Statorstroms gleich null geliefert hat.

11. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der identifizierte Parameter eine Rotorzeitkonstante ist, wobei
das Messen den Schritt des Messens des maximalen Stroms (i_{sdz_max}) während des Null-Spannungs-Vektors und dem Zeitpunkt (t_z) seines Vorliegens aufweist,
das Verfahren weiterhin die Schritte aufweist

a) Bereitstellen von DC-Magnetisierung an die Induktionsmaschine mit einem zweiten Magnetisierungsstrom,
b) Steuern der Leistungshalbleiter des Wechselrichters in den Aus-Zustand,
c) Steuern aller Ausgangsphasen des Wechselrichters auf das gleiche Potential um einen Null-Spannungs-Vektor bereitzustellen, wenn der Statorstrom auf den Wert des gemessenen maximalen Stroms gesunken ist, und Bestimmen der Ableitung des Statorstroms sofort nach dem Steuern der Ausgangsschalter,

Wechseln des Wertes des zweiten Magnetisierungsstroms ($i_{dc_magn,\ 2}$) und Wiederholen der oben genannten Schritte a), b) und c) wenn die bestimmte Ableitung des Statorstroms nicht null ist,
Berechnen der Rotorzeitkonstante aus
dem Einschaltzeitpunkt (t_{z0}), zu dem der Null-Spannungs-Vektor aktiviert ist,
dem Zeitpunkt (t_z) des maximalen Stroms des Statorstroms während des Null-Vektors,
dem Zeitpunkt (t_0), zu dem die Leistungshalbleiter in den Aus-Zustand gesteuert werden,
der Größe des Magnetisierungsstroms ($i_{dc_magn,1}$), welcher für die Magnetisierung genutzt wurde, der den gemessenen maximalen Strom (i_{sdz_max}) geliefert hat,
der Größe des zweiten Magnetisierungsstroms ($i_{dc_magn,2}$), welcher die Ableitung des Statorstroms gleich null geliefert hat, und
einem anfänglichen Wert der Rotorzeitkonstante.

12. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** die Rotorzeitkonstante iterativ berechnet wird unter Verwendung der berechneten Rotorzeitkonstante als einem anfänglichen Wert der Rotorzeitkonstante in der Iteration.

13. Verfahren nach einem der vorhergehenden Ansprüche 1 bis 12, **dadurch gekennzeichnet, dass** nach der Magnetisierung, anstatt Steuern der Leistungshalbleiter des Wechselrichters in den Aus-Zustand, die Leistungshalbleiter gesteuert werden, um einen Spannungs-Vektor hervor zu bringen, der eine umgekehrte Polarität hat im Vergleich zu dem Spannungs-Vektor, der für die Magnetisierung genutzt wurde.

14. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der identifizierte Parameter eine Rotorzeitkonstante ist, wobei
das Messen den Schritt des Messens des maximalen Stroms (i_{sdz_max}) während des Null-Spannungs-Vektors und dem Zeitpunkt (t_{z1}) seines Vorliegens aufweist,
das Verfahren weiterhin die Schritte aufweist

a) Bereitstellen von DC-Magnetisierung an die Induktionsmaschine mit einem zweiten Magnetisierungsstrom ($i_{dc_magn,2}$),
b) Steuern der Leistungshalbleiter des Wechselrichters in den Aus-Zustand,
c) Steuern aller Ausgangsphasen des Wechselrichters auf das gleiche Potential um einen Null-Spannungs-Vektor bereitzustellen, und Messen des maximalen Wertes des Statorstroms während des Null-Spannungs-Vektors und dem Zeitpunkt (t_{z2}) seines Vorliegens,

Wechseln des Wertes des zweiten Magnetisierungsstroms ($i_{dc_magn,\ 2}$) und Wiederholen der oben genannten Schritte a), b) und c) wenn der maximale Wert des Statorstroms nicht gleich dem maximalen Strom (i_{sdz_max}) ist, welcher während der ersten Magnetisierung gemessen wurde,
Berechnen der Rotorzeitkonstante aus
dem Zeitpunkt (t_{z1}, t_{z2}) des maximalen Stroms (i_{sdz_max}) des Statorstroms während der Null-Vektoren,
der Größe des Magnetisierungsstroms ($i_{dc_magn,1}$), welcher für die Magnetisierung genutzt wurde, der den gemessenen maximalen Strom (i_{sdz_max}) geliefert hat, und
der Größe des zweiten Magnetisierungsstroms ($i_{dc_magn,2}$), welcher einen Statorstrom geliefert hat, der den maximalen Wert gleich zu dem der ersten Magnetisierung hatte.

15. Verfahren nach Anspruch 14, **dadurch gekennzeichnet, dass** in der Berechnung der Rotorzeitkonstante die Zeitpunkte (t_{z01}, t_{z02}), zu denen die Null-Vektoren eingenommen wurden, verwendet werden, anstatt der Zeitpunkte (t_{z1}, t_{z2}) der maximalen Ströme.

16. Verfahren nach einem der Ansprüche 14 oder 15, **dadurch gekennzeichnet, dass** anstatt Wechseln des Wertes des Magnetisierungsstroms, der Zeitpunkt, zu dem der Null-Vektor eingenommen wird, gewechselt wird, um einen Statorstrom, der einen maximalen Wert gleich zu dem des maximalen Stroms gemessen während der ersten Magnetisierung hat, zu erzielen.

17. Vorrichtung zum Identifizieren von Parametern für eine Induktionsmaschine wenn die Induktionsmaschine mit den Ausgangsphasen eines Spannungsquellenwechselrichters verbunden ist und die Induktionsmaschine im Stillstandszustand ist, **gekennzeichnet durch** Mittel, die ausgeführt sind zum:

Bereitstellen von DC-Magnetisierung (i_{dc_magn}) an die Induktionsmaschine mit dem Wechselrichter, bis der Fluss der Maschine einen stabilen Zustand erreicht,
Steuern der Leistungshalbleiter des Wechselrichters in einen Aus-Zustand für ein bestimmtes Zeitintervall (t_0 — t_{z0}) nach der DC-Magnetisierung,
Steuern aller Ausgangsphasen des Wechselrichters auf das gleiche Potential zum Bereitstellen eines Null-Spannungs-Vektors nach der Passivierung der Wechselrichterleistungsstufe,
Messen des Statorstroms (i_{sd}) während der Anbringungszeit des Null-Spannungs-Vektors, und
Bestimmen von Parametern der Induktionsmaschine aus dem Statorstrom (i_{sd}), welcher während des Null-Spannungs-Vektors gemessen ist.

Revendications

1. Procédé d'identification de paramètres d'une machine à induction lorsque la machine à induction est connectée aux phases de sortie d'un inverseur de source de tension et lorsque la machine à induction se trouve dans un état d'immobilisation, **caractérisé par** les étapes consistant à :

fournir un courant de magnétisation DC (i_{dc_magn}) à la machine à induction avec l'inverseur, jusqu'à ce que le flux de la machine atteigne un régime permanent ; puis
maintenir les semi-conducteurs de puissance de l'inverseur à l'état bloqué pendant un certain intervalle de temps ($t_{0_}$ t_{z0}) ; et ensuite
maintenir toutes les phases de sortie de l'inverseur au même potentiel pour fournir un vecteur de tension nulle ;
mesurer le courant de stator (i_{sd}) pendant le vecteur de tension nulle ; et
déterminer les paramètres de la machine à induction à partir du courant de stator (i_{sd}) mesuré pendant le vecteur de tension nulle.

2. Procédé selon la revendication 1, **caractérisé en ce que** le paramètre identifié est la constante de temps du rotor (τ_r), dans lequel :

le mesurage du courant de stator (i_{sd}) comprend les étapes consistant à :

mesurer le courant maximum (i_{sdz_max}) pendant le vecteur de tension nulle et son instant de temps (t_z) ;
déterminer la constante de temps du rotor (τ_r) à partir :

de l'amplitude du courant de magnétisation DC (i_{dc_magn}) ;
des résistances du stator et du rotor (R_S, R_R) de la machine ;
du courant maximum déterminé (i_{sdz_max}) et de son instant de temps (t_z) ;
de l'instant de temps (t_0) où les semi-conducteurs de puissance sont maintenus à l'état bloqué ; et
de la tension de seuil (u_{th}) de l'inverseur.

3. Procédé selon la revendication 1, **caractérisé en ce que** le paramètre identifié est une constante de temps du rotor (τ_r), dans lequel :

le mesurage du courant de stator comprend les étapes consistant à :

mesurer le courant maximum (i_{sdz_max}) pendant le vecteur de tension nulle et son instant de temps (t_z) ;
déterminer numériquement la constante de temps du rotor en utilisant un algorithme d'itération à partir :

de l'amplitude du courant de magnétisation DC (i_{dc_magn}) ;
des résistances du stator et du rotor (R_S, R_R) de la machine ;
du courant maximum déterminé (i_{sdz_max}) et de son instant de temps (t_z) ;
de l'instant de temps (t_{z0}) où le vecteur nul est mis en service ;
de l'instant de temps (t_0) où les semi-conducteurs de puissance sont maintenus à l'état bloqué ;
de la tension de seuil (u_{th}) de l'inverseur ; et
d'une estimation initiale de la constante de temps du rotor.

4. Procédé selon la revendication 1, **caractérisé en ce que** le paramètre identifié est la constante de temps du rotor (τ_r), dans lequel :

la mesure du courant de stator comprend la mesure du courant maximum (i_{sdz_max}) et de son instant de temps (t_z) ;
la mesure du courant maximum est répétée en utilisant le même courant de magnétisation (i_{dc_magn}) avec différents instants de mise en route (t_{z01}, t_{z02}) pour le vecteur de tension nulle :

déterminer la constante de temps du rotor à partir :

des instants de temps mesurés ($t_{z1,}$ t_{z2}) des courants maximums ;
des courants maximums mesurés (i_{sdz_max1}, i_{sdz_max2}) ;
des résistances du stator et du rotor (R_S, R_R) de la machine ; et
de la tension de seuil (u_{th}) de l'inverseur.

5. Procédé selon la revendication 1, **caractérisé en ce que** le paramètre identifié est une constante de temps du rotor (τ_r), dans lequel :

la mesure du courant de stator comprend la mesure du courant maximum (i_{sdz_max}) ;

la mesure du courant maximum est répétée en utilisant le même courant de magnétisation (i_{dc_magn}) avec différents instants de mise en route (t_{z01}, t_{z02}) pour le vecteur de tension nulle ;
déterminer la constante de temps du rotor à partir :

des instants de temps de mise en route (t_{z01}, t_{z02}) pour les vecteurs de tension nulle ;
des courants maximums mesurés (i_{sdz_max1}, i_{sdz_max2}) ;
des résistances du stator et du rotor (R_S, R_R) ; et
de la tension de seuil (u_{th}) de l'inverseur.

6. Procédé selon la revendication 1, **caractérisé en ce que** le paramètre identifié est la résistance du rotor (R_R) de la machine, dans lequel :

Le maintien des phases de sortie de l'inverseur au même potentiel comprend une étape dans laquelle les phases de sortie sont maintenues au même potentiel de sorte que la dérivée du courant de stator (i_{sd}) est nulle immédiatement après la commutation ; et
le mesurage du courant de stator (i_{sd}) comprend une étape dans laquelle le courant de stator est mesuré immédiatement après la commutation, dans lequel la résistance du rotor (R_R) est calculée à partir :

du courant de stator mesuré (i_{sd0}) ;
de l'amplitude du courant de magnétisation (i_{dc_magn}) ;
de la tension de seuil (u_{th}) de l'inverseur ; et
de la résistance du stator (R_S) de la machine.

7. Procédé selon la revendication 1, **caractérisé en ce que** le paramètre identifié est la résistance du rotor (R_R) de la machine, dans lequel :

Le maintien des phases de sortie au même potentiel comprend une étape dans laquelle les phases de sortie sont maintenues au même potentiel de sorte que la dérivée du courant de stator (i_{sd}) est nulle immédiatement après la commutation ;
le mesurage du courant de stator comprend une étape dans laquelle le courant de stator est mesuré immédiatement après la commutation ; et
les étapes sont répétées avec différents courants de magnétisation ($i_{dc_magn,1}$, $i_{dc_magn,2}$, $i_{dc_magn,n}$) une ou plusieurs fois pour obtenir deux valeurs ou plus du courant de stator ($i_{sd0,1}$, $i_{sd0,2}$, $i_{sd0,n}$) et les amplitudes des courants de magnétisation ($i_{dc_magn,1}$, $i_{dc_magn,2}$, $i_{dc_magn,n}$) ;
dans lequel la résistance du rotor est calculée à partir :

des courants de stator mesurés ($i_{sd0,1}$, $i_{sd0,2}$, $i_{sd0,n}$) ;
des amplitudes des courants de magnétisation ($i_{dc_magn,1}$, $i_{dc_magn,2}$, $i_{dc_magn,n}$) ; et
de la résistance du stator (R_S) de la machine.

8. Procédé selon la revendication 1, **caractérisé en ce que** le paramètre identifié est la tension de seuil (u_{th}) de l'inverseur, dans lequel :

Le maintien des phases de sortie au même potentiel comprend une étape dans laquelle les phases de sortie sont maintenues au même potentiel de sorte que la dérivée du courant de stator est égale à zéro immédiatement après la commutation ; et
le mesurage du courant de stator comprend une étape dans laquelle le courant de stator est mesuré immédiatement après la commutation, dans lequel la tension de seuil de l'inverseur est calculée à partir :

du courant de stator mesuré (i_{sd0}) ;
de l'amplitude du courant de magnétisation (i_{dc_magn}) ;
de la résistance du stator (R_S) de la machine ; et
de la résistance du stator (R_S) de la machine.

9. Procédé selon la revendication 1, **caractérisé en ce que** le paramètre identifié est une tension de seuil (u_{th}) de l'inverseur, dans lequel :

Le maintien des phases de sortie au même potentiel comprend une étape dans laquelle les phases de sortie

sont maintenues au même potentiel de sorte que la dérivée du courant de stator est égale à zéro immédiatement après la commutation ;
le mesurage du courant de stator comprend une étape dans laquelle le courant de stator est mesuré immédiatement après la commutation ; et
les étapes sont répétées avec différents courants de magnétisation une ou plusieurs fois pour obtenir deux valeurs ou plus du courant de stator ($i_{sd0,1}$, $i_{sd0,2}$, $i_{sd0,n}$) et les amplitudes des courants de magnétisation ($i_{dc_magn,1}$, $i_{dc_magn,2}$, $i_{dc_magn,n}$) ;
dans lequel la tension de seuil de l'inverseur est calculée à partir :

des courants de stator mesurés ($i_{sd0,1}$, $i_{sd0,2}$, $i_{sd0,n}$) ;
des amplitudes des courants de magnétisation ($i_{dc_magn,1}$, $i_{dc_magn,2}$, $i_{dc_magn,n}$) ; et
de la résistance du stator (R_S) de la machine.

10. Procédé selon la revendication 1, **caractérisé en ce que** le paramètre identifié est une constante de temps du rotor, dans lequel :

le mesurage comprend une étape consistant à mesurer le courant maximum (i_{sdz_max}) pendant le vecteur de tension nulle et son instant de temps (t_z) ;
le procédé comprend en outre les étapes consistant à :

a) fournir une magnétisation DC à la machine à induction avec un deuxième courant de magnétisation ;
b) maintenir les semi-conducteurs de puissance de l'inverseur à l'état bloqué ;
c) maintenir toutes les phases de sortie de l'inverseur au même potentiel pour fournir un vecteur de tension nulle lorsque le courant de stator a chuté jusqu'à la valeur du courant maximum mesuré (i_{sdz_max}), et déterminer la dérivée du courant de stator immédiatement après que le maintien de sortie a commuté ;

modifier la valeur du deuxième courant de magnétisation ($i_{dc_magn,2}$) et répéter les étapes ci-dessus a), b) et c) si la dérivée déterminée du courant de stator n'est pas égale à zéro ;
calculer la constante de temps du rotor à partir :

de l'instant de temps (t_z) du courant maximum (i_{sdz_max}) du courant de stator pendant le vecteur nul ;
de l'instant de temps (t_0) où les semi-conducteurs de puissance sont maintenus à l'état bloqué ;
de l'amplitude du courant de magnétisation ($i_{dc_magn,1}$) utilisé dans la magnétisation qui a produit le courant maximum mesuré (i_{sdz_max}) ; et
de l'amplitude du deuxième courant de magnétisation ($i_{dc_magn,2}$) qui a produit la dérivée nulle du courant de stator.

11. Procédé selon la revendication 1, **caractérisé en ce que** le paramètre identifié est une constante de temps du rotor, dans lequel :

le mesurage comprend une étape consistant à mesurer le courant maximum (i_{sdz_max}) pendant le vecteur de tension nulle et son instant de temps (t_z) ;
le procédé comprend en outre les étapes consistant à :

a) fournir une magnétisation DC à la machine à induction avec un deuxième courant de magnétisation ;
b) maintenir les semi-conducteurs de puissance de l'inverseur à l'état bloqué ;
c) maintenir toutes les phases de sortie de l'inverseur au même potentiel pour fournir un vecteur de tension nulle lorsque le courant de stator a chuté jusqu'à la valeur du courant maximum mesuré, et déterminer la dérivée du courant de stator immédiatement après que le maintien de sortie a commuté ;

modifier la valeur du deuxième courant de magnétisation ($i_{dc_magn,2}$) et répéter les étapes ci-dessus a), b) et c) si la dérivée déterminée du courant de stator n'est pas égale à zéro ;
calculer la constante de temps du rotor à partir :

de l'instant de temps de mise en route (t_{z0}) lorsque le vecteur de tension nulle est activé ;
de l'instant de temps (t_z) du courant maximum du courant de stator pendant le vecteur nul ;
de l'instant de temps (t_0) où les semi-conducteurs de puissance sont maintenus à l'état bloqué ;
de l'amplitude du courant de magnétisation ($i_{dc_magn,1}$) utilisé dans la magnétisation qui a produit le courant

maximum mesuré (i_{sdz_max}) ;
de l'amplitude du deuxième courant de magnétisation ($i_{dc_magn,2}$) qui a produit la dérivée égale à zéro du courant de stator ; et
d'une valeur initiale de la constante de temps du rotor.

12. Procédé selon la revendication 11, **caractérisé en ce que** la constante de temps du rotor est calculée de manière itérative en utilisant la constante de temps du rotor calculée en tant que valeur initiale de la constante de temps du rotor dans l'itération.

13. Procédé selon l'une quelconque des revendications précédentes 1 à 12, **caractérisé en ce que**, après la magnétisation, au lieu de maintenir les semi-conducteurs de puissance de l'inverseur à l'état bloqué, les semi-conducteurs de puissance sont maintenus de façon à produire un vecteur de tension qui présente une polarité opposée comparativement au vecteur de tension utilisé dans la magnétisation.

14. Procédé selon la revendication 1, **caractérisé en ce que** le paramètre identifié est la constante de temps du rotor, dans lequel :

le mesurage comprend l'étape consistant à mesurer le courant maximum (i_{sdz_max}) pendant le vecteur de tension nulle et son instant de temps (t_{z1}) ;
le procédé comprend en outre les étapes consistant à :

a) fournir une magnétisation DC à la machine à induction avec un deuxième courant de magnétisation ($i_{dc_magn,2}$) ;
b) maintenir les semi-conducteurs de puissance de l'inverseur à l'état bloqué ;
c) maintenir toutes les phases de sortie de l'inverseur au même potentiel pour fournir un vecteur de tension nulle, et mesurer la valeur maximum du courant de stator pendant le vecteur de tension nulle et son instant de temps (t_{z2}) ;

modifier la valeur du deuxième courant de magnétisation ($i_{dc_magn,2}$) et répéter les étapes ci-dessus a), b) et c) si la valeur maximum du courant de stator n'est pas égale au courant maximum (i_{sdz_max}) mesuré pendant la première magnétisation ;
calculer la constante de temps du rotor à partir :

de l'instant de temps (t_{z1}, t_{z2}) du courant maximum (i_{sdz_max}) du courant de stator pendant les vecteurs nuls ;
de l'amplitude du courant de magnétisation ($i_{dc_magn,1}$) utilisé dans la magnétisation qui a produit le courant maximum mesuré (i_{sdz_max}) ; et
de l'amplitude du deuxième courant de magnétisation ($i_{dc_magn,2}$) qui a produit un courant de stator qui a présenté une valeur maximum égale à celle de la première magnétisation.

15. Procédé selon la revendication 14, **caractérisé en ce que**, dans le calcul de la constante de temps du rotor, les instants de temps (t_{z01}, t_{z02}) où les vecteurs nuls ont été mis en service sont utilisés, au lieu des instants de temps (t_{z1}, t_{z2}) des courants maximum.

16. Procédé selon la revendication 14 ou 15, **caractérisé en ce que**, au lieu de modifier la valeur du courant de magnétisation, l'instant de temps où le vecteur nul est mis en service est modifié pour obtenir un courant de stator qui présente une valeur maximum égale à celle du courant maximum mesuré pendant la première magnétisation.

17. Agencement pour identifier des paramètres d'une machine à induction lorsque la machine à induction est connectée aux phases de sortie d'un inverseur de source de tension et lorsque la machine à induction se trouve dans un état d'immobilisation, **caractérisé par** des moyens configurés pour :

fournir une magnétisation DC (i_{dc_magn}) à la machine à induction avec l'inverseur, jusqu'à ce que le flux de la machine atteigne un régime permanent ;
maintenir les semi-conducteurs de puissance de l'inverseur à l'état bloqué pendant un certain intervalle de temps (t_0— t_{z0}) après la magnétisation DC ;
maintenir toutes les phases de sortie de l'inverseur au même potentiel pour fournir un vecteur de tension nulle après la passivation de l'étage de puissance de l'inverseur ;
mesurer le courant de stator (i_{sd}) pendant la durée d'application du vecteur de tension nulle ; et

déterminer les paramètres de la machine à induction à partir du courant de stator (i_{sd}) mesuré pendant le vecteur de tension nulle.

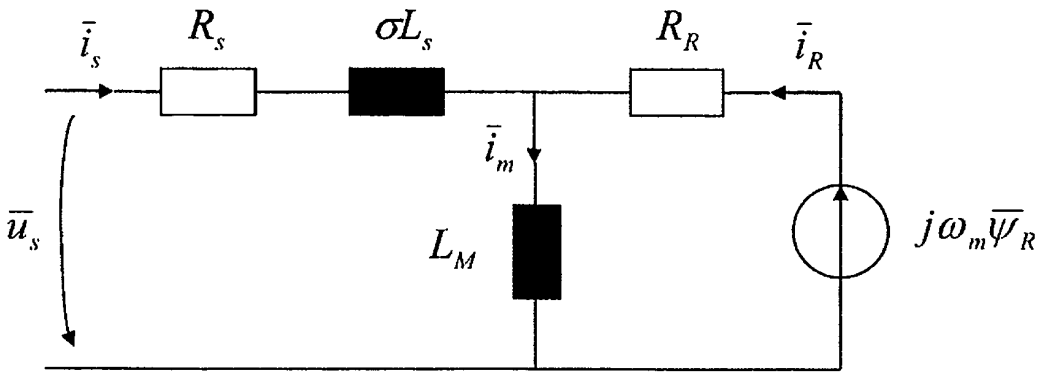

$\bar{i}_s$
R_s
σL_s
R_R
$\bar{i}_R$
$\bar{i}_m$
$\bar{u}_s$
L_M
$j\omega_m\bar{\psi}_R$

FIG 1

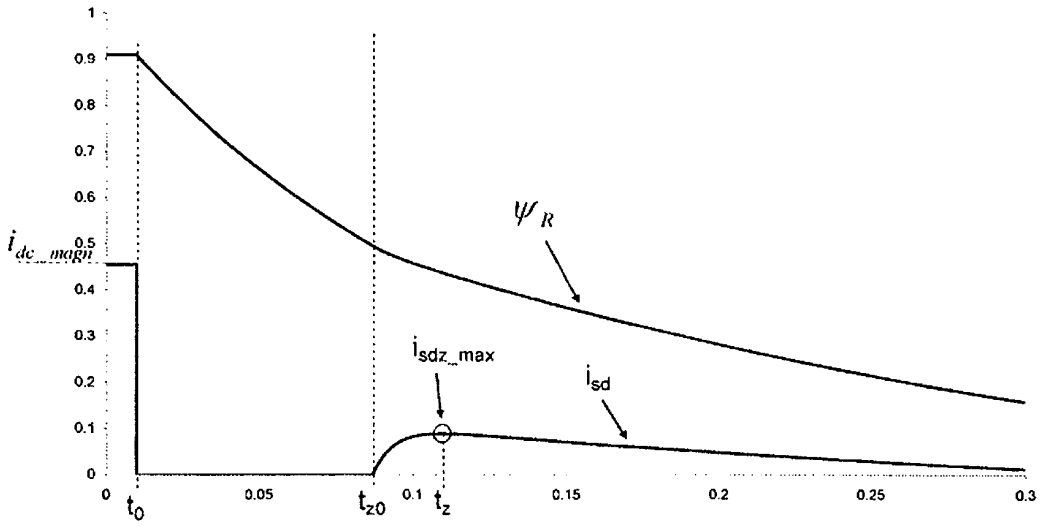

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
i_{dc_magn}
ψ_R
i_{sdz_max}
i_{sd}
0
t_0
0.05
t_{z0}
0.1
t_z
0.15
0.2
0.25
0.3

FIG 2

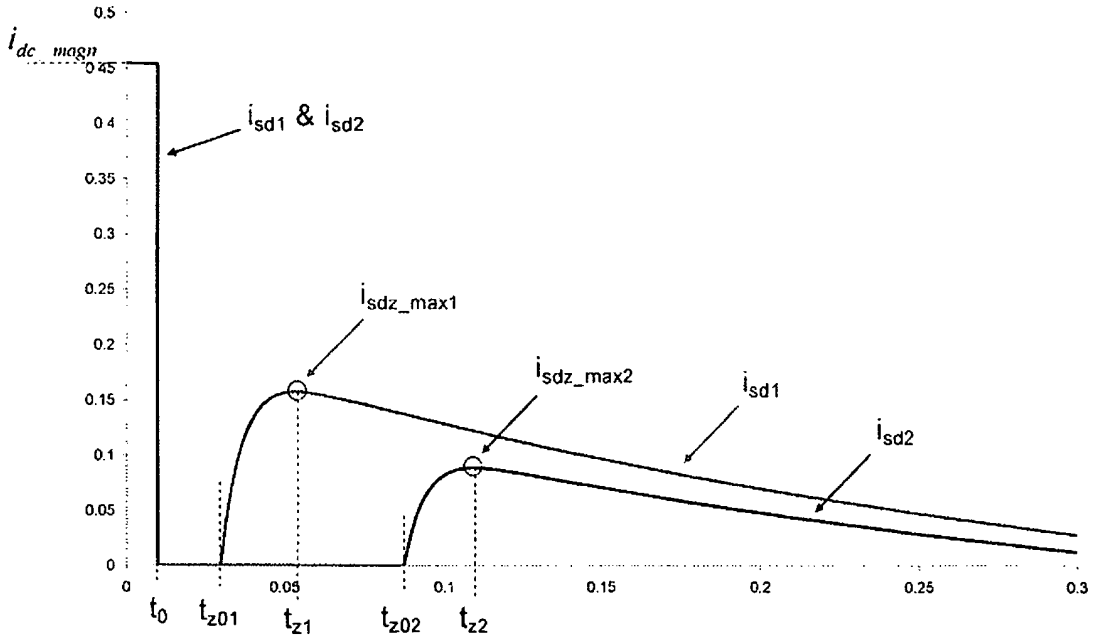

i_{dc_magn}
i_{sd1} & i_{sd2}
i_{sdz_max1}
i_{sdz_max2}
i_{sd1}
i_{sd2}
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.05
0.1
0.15
0.2
0.25
0.3
t_0
t_{z01}
t_{z1}
t_{z02}
t_{z2}

FIG 3

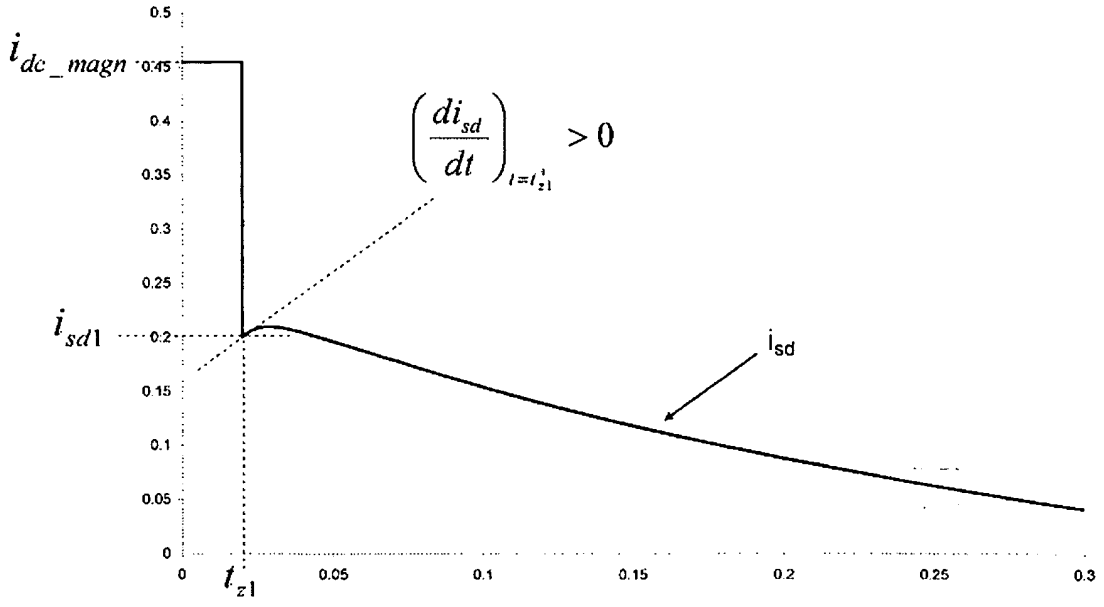

i_{dc_magn}
$\left(\frac{di_{sd}}{dt}\right)_{t=t_{z1}} > 0$
i_{sd1}
i_{sd}
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.05
0.1
0.15
0.2
0.25
0.3
t_{z1}

FIG 4

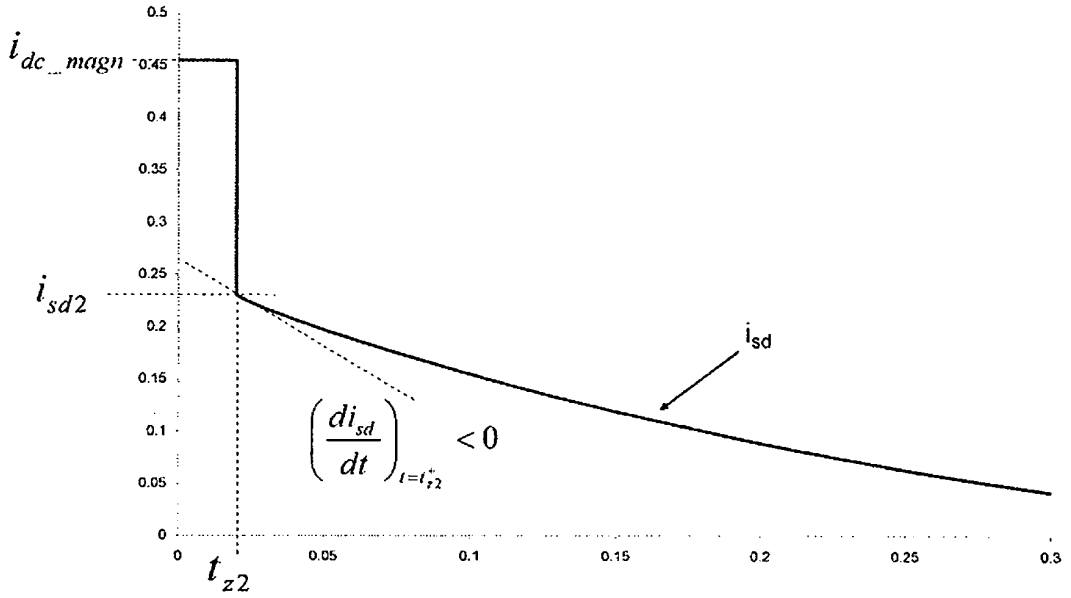

i_{dc_magn}
i_{sd2}
t_{z2}
$\left(\frac{di_{sd}}{dt}\right)_{t=t_{z2}^{+}} < 0$
i_{sd}
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.05
0.1
0.15
0.2
0.25
0.3

FIG 5

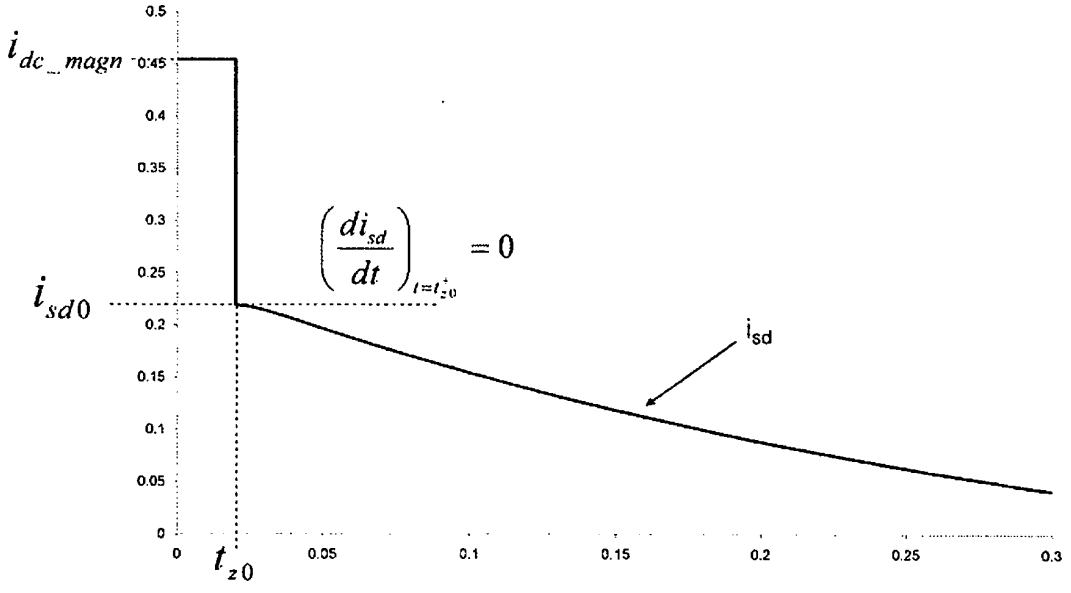

i_{dc_magn}
i_{sd0}
t_{z0}
$\left(\frac{di_{sd}}{dt}\right)_{t=t_{z0}^{+}} = 0$
i_{sd}
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.05
0.1
0.15
0.2
0.25
0.3

FIG 6

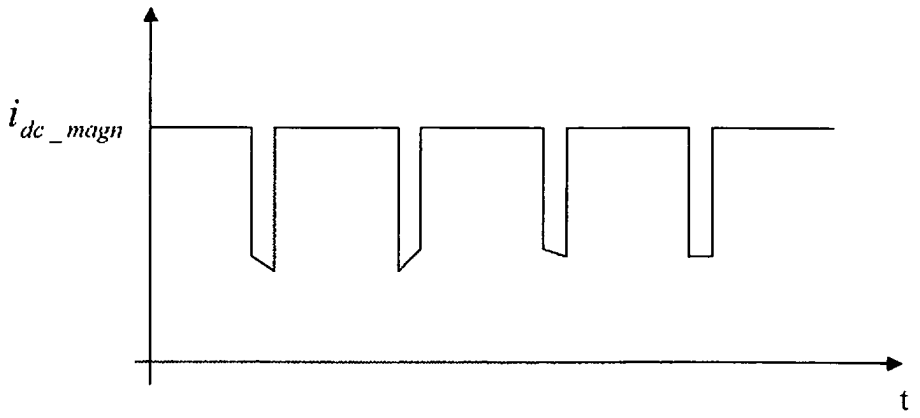

i_{dc_magn}
t

FIG 7

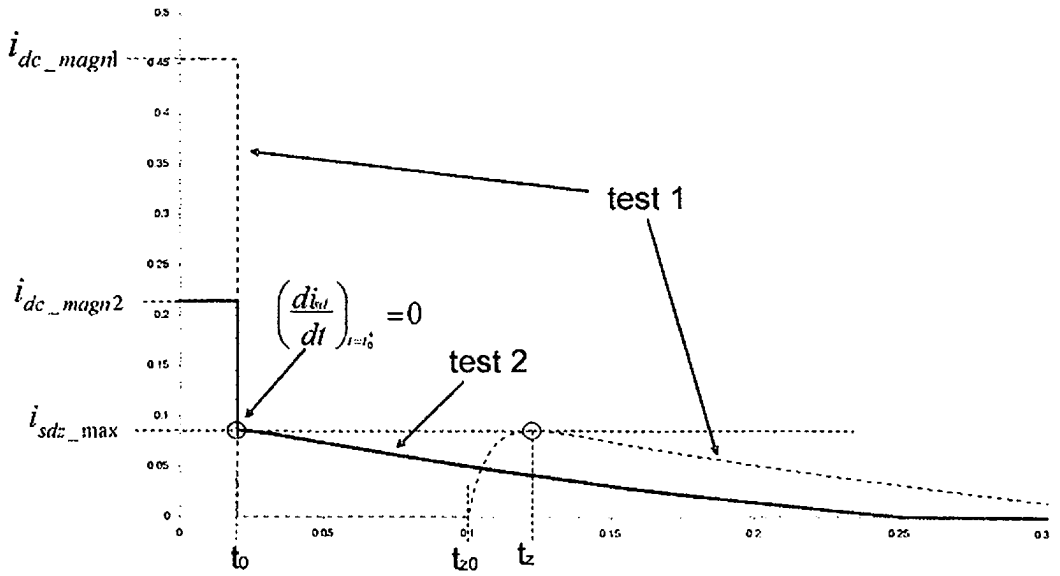

i_{dc_magn1}
i_{dc_magn2}
i_{sdz_max}
$\left(\frac{di_{sd}}{dt}\right)_{t=t_0^+}=0$
test 1
test 2
t_0
t_{z0}
t_z

FIG 8

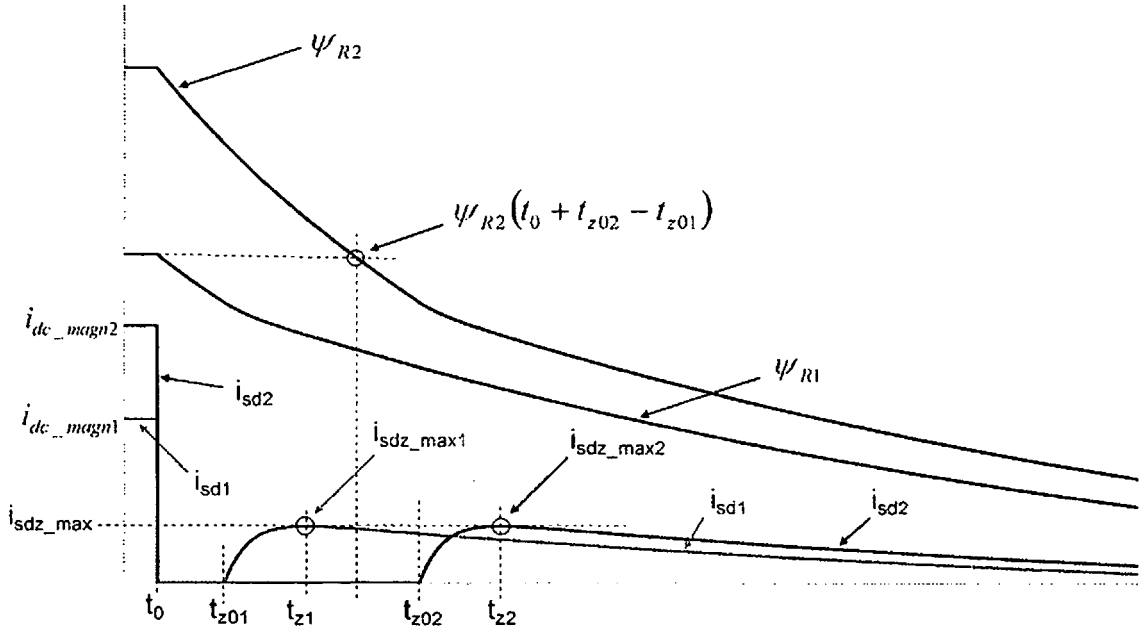

ψ_{R2}
$\psi_{R2}(t_0 + t_{z02} - t_{z01})$
ψ_{R1}
i_{dc_magn2}
i_{dc_magn1}
i_{sd2}
i_{sd1}
i_{sdz_max1}
i_{sdz_max2}
i_{sdz_max}
t_0
t_{z01}
t_{z1}
t_{z02}
t_{z2}

FIG 9

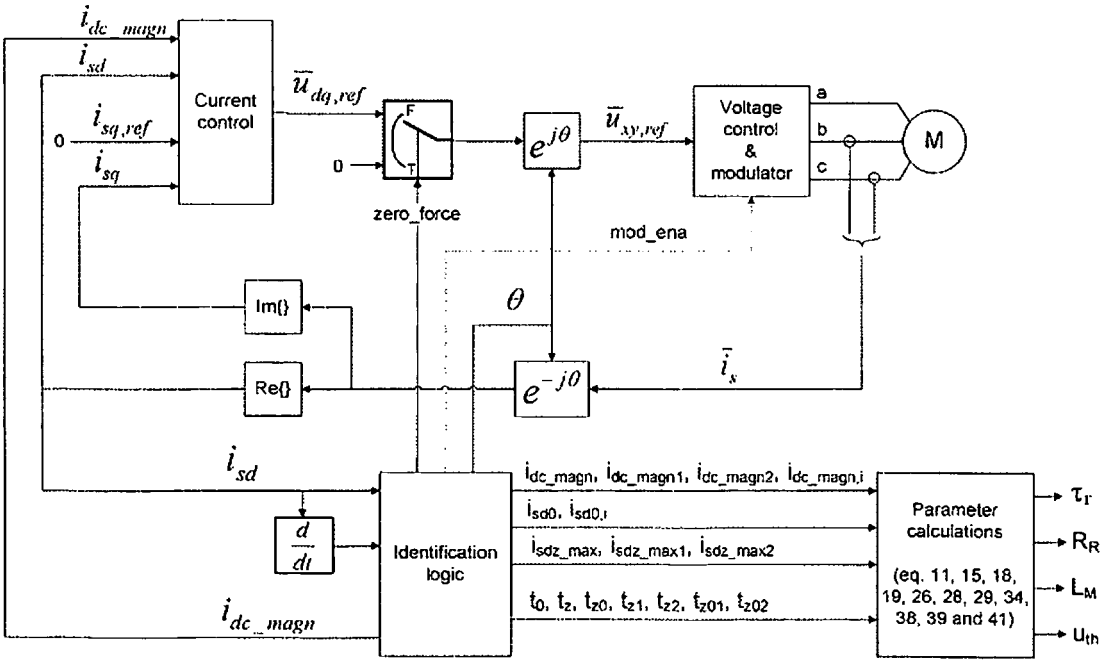

i_{dc_magn}
i_{sd}
$i_{sq,ref}$
0
i_{sq}
Current control
$\bar{u}_{dq,ref}$
F
T
0
zero_force
$e^{j\theta}$
$\bar{u}_{xy,ref}$
Voltage control & modulator
a
b
c
M
mod_ena
θ
Im{}
Re{}
$e^{-j\theta}$
$\bar{i}_s$
i_{sd}
$\frac{d}{dt}$
Identification logic
i_{dc_magn}
i_{dc_magn}, i_{dc_magn1}, i_{dc_magn2}, $i_{dc_magn,i}$
i_{sd0}, $i_{sd0,i}$
i_{sdz_max}, i_{sdz_max1}, i_{sdz_max2}
t_0, t_z, t_{z0}, t_{z1}, t_{z2}, t_{z01}, t_{z02}
Parameter calculations
(eq. 11, 15, 18, 19, 26, 28, 29, 34, 38, 39 and 41)
τ_r
R_R
L_M
u_{th}

FIG 10

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- DE 10254940 **[0009]**
- US 5594670 A **[0010]**